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February 13-14, 1996

ECO-REFRIGERATION

Conference on Hydrocarbon Fluids in Domestic and Commercial Refrigeration Appliances

ORGANIZED BY

Ministry of Environment and Forests
Government of India

Swiss Development Cooperation (SDC)
Government of Switzerland

Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ)
Technical Cooperation of the Government of Germany

FACILITATED BY

Tata Energy Research Institute (TERI)

Conference Documentation

Eco-Refrigeration Programme

13 February 1996

08 30	**Registration**
09 30	**Inaugural Session**
	Welcome Address
09 30–09 40	*Anil Agarwal*, Director, Ozone Cell, Ministry of Environment and Forests, Government of India, New Delhi
	Address
09 40–09 45	*Guy Ducrey*, Ambassador of Switzerland, New Delhi
09 45–09 50	*Frank Elbe*, Ambassador of Germany, New Delhi
	Remarks
09 50–09 55	*Peter Baz*, Head, GATE, GTZ, Germany
	Keynote Address
09 55–10 05	*A H Tobaccowallah*, Chairman, Voltas Ltd Bombay
	Address by Chief Guest
10 05–10 20	*Rajesh Pilot*, Honourable Minister of State for Environment and Forests, Government of India, New Delhi
	Concluding Remarks and Vote of Thanks
10 20–10 25	*Urs Heierli*, Counsellor and Head of Development Cooperation, Embassy of Switzerland, New Delhi
10 25–10 55	**Tea/Coffee**
Session I	
10 55	**Eco-Refrigeration: Cooperation — Experience and Background**
	Session Chairperson *Urs Heierli*, Counsellor and Head of Development Cooperation, Embassy of Switzerland, New Delhi
	Eco-refrigeration: global state of art
11 00–11 15	*Othmar Schwank*, INFRAS, Switzerland
	Eco-refrigeration: highlights fromChina
11 15–11 25	*Klaus Meyersen*, GTZ, Germany
11 25-11 35	*Wang Dongning*, Haier Group, China
	Eco-refrigeration: highlights from India
11 35–11 45	*R S Agarwal*, IIT Delhi and
11 45-11 55	*R S Iyer*, Voltas Ltd , Bombay
	New global initiatives
11 55-12 05	*Bill Rahill*, The World Bank, USA
12 05–12 20	**Question–Answer Session**
Session II	
12 20	**Sythentic and Natural Fluids in Domestic and Commercial Refrigeration**
	Session Chairperson *V M Crishna*, Managing Director, Godrej-GE, Bombay
	HC600a, HC blends and HFC134a: performance, manufacturing, costs from the compressor point of view
12 25–12 55	*Edoardo Biscaldi*, Necchi Compressori, Italy
	HFC134a and hydrocarbon appliances in domestic refrigeration: market trends, conversion
12 55–13 25	*Juergen Melzer*, Liebherr, Germany
13 25–13 45	**Question–Answer Session**
13 45–14 45	**Lunch**
14 45	**Session II continued**
	Use of synthetic and natural fluids in commercial refrigeration appliances
14 45–15 15	*Stephan Sicars*, FKW (Research Centre for Refrigeration Technologies and Heat Pumps), Germany
	Hydrocarbon refrigerants: properties, purity and safe handling
15 15–15 45	*Jane Gartshore(Mrs)*, Cool Concerns, UK and *Jack Buswell*, Calor Gas, UK
15 45–16 15	**Question–Answer session**
16 15–16 45	**Tea/Coffee**

16 45–17 45 **Panel Discussion on Synthetic and Natural Fluids in Domestic and Commercial Refrigeration**

Panel Members
A S Ghoshal, Joint CCoE
M Srivastava, OISD
B J Wadia, Godrej–GE
K V N Rao, Kelvinator
M K Chanderasekhar, BPL
K Venkateswarlu, Sriram
V G Sardesai, Kirloskar
S Devotta, NCL
Stephan Sicars, FKW
Jane Gartshore, Cool Concern
Jack Buswell, Calor Gas
Juergen Melzer, Liebherr
Edoardo Biscaldi, Necchi

Panel Chairperson
S N Tripathi, Chief Executive-Allwyn unit, Voltas, Hyderabad

17 45–18 15 **Demonstration of servicing equipment for hydrocarbon refrigerators**
Liebherr, Germany and
Information on the energy-efficient R600a refrigerator
Haier, China

18 45 **Reception**
(time and venue to be confirmed)

14th February 1996

Session III

09 30 **Cyclopentane Foam Blowing**

Session Chairperson
M Sarangapani, Chairman, Polyurethane Council of India

Properties of Cyclopentane blown foam
09 35–10 05 *Mike Jeffs*, ICI, Belgium

Cyclopentane foaming on an industrial scale: introduction, retrofitting
10 05–10 25 *Massimo Castiglioni*, Afros Cannon, Italy

Cyclopentane foaming on an industrial scale: technical solutions for new installations
10 25–10 45 *Karl Giessler*, Plasttechnik Greiz, Germany

10 45–11 15 **Question–Answer session**

11.15–11 45 **Tea/Coffee**

Safe handling and operations during Cyclopentane foaming
11 45–12 15 *J J Gardner*, ICI, Belgium

12 15–13 15 **Panel Discussion on Cyclopentane Foam: Properties, Formulations, Installation and Safety**

Panel Members
A S Ghoshal, Joint CCoE
M Srivastava, OISD
Walter Arosio, Whirlpool-Kelvinator
M S Dhaber, Videocon
J Kishan Rao, BPL
A Gurshaney, Maharaja
N T Desai, Godrej–GE
R S Iyer, Voltas Ltd
S K Mukherjee, Ozone Cell
Massimo Castiglioni, Afros Cannon
Karl Giessler, Greiz
Mike Jeffs, ICI
J J Gardner, ICI

Panel Chairperson
Lalitha B Singh(Mrs), Advisor, Ministry of Chemicals & Petrochemicals

13 15–14 15 **Lunch**

Session IV

14 15 **Servicing of Refrigeration Appliances and Training Needs**

Session Chairperson
Kamal Sahdev, President, AIACRA

Organization and skills in the Indian RAC service market
14 20–14 35 *E Prasad*, Consultant, SDC, India

Concepts & experiences in servicing of refrigeration appliances
14 35–15 05 *Juergen Melzer*, Liebherr, Germany

	Training needs for servicing of refrigeration appliances
15 05–15.35	*Jane Gartshore(Mrs)*, Cool Concerns, UK
15 35–15.55	**Question-Answer session**
15 55–16 20	**Tea/Coffee**
16 20–17 15	**Panel Discussion on Servicing of Refrigeration Appliances and Training Needs**
	Panel Members *A S Ghoshal*, Joint CCoE *S K Kinra*, Office of the DC SSI *V Subramaniam*, Godrej-GE *R Kumar*, Voltas Ltd. *Varadarajan*, Kelvinator *D H Dixit*, Videocon *K Sahdev*, Trikuta Coolings *J Singh*, Hindustan Refrigeration *S S Sidhu*, Sidwal Refrigeration *E Prasad*, Consultant, SDC *V Joshi(Mrs)*, SDC *Stephan Sicars*, FKW *Jane Gartshore(Mrs)*, Cool Concerns *Juergen Melzer*, Liebherr
	Panel Chairperson *Dr Ajay Mathur*, Senior Fellow, TERI
	Concluding Remarks on Hydrocarbon Conference
17 15	*Othmar Schwank*, INFRAS, Switzerland
17 30	**End of Conference**

Conference Moderators

Dr Urs Heierli, SDC

Dr Ajay Mathur, TERI

ECO-REFRIGERATION

CONFERENCE ON HYDROCARBON FLUIDS IN DOMESTIC AND COMMERCIAL REFRIGERATION APPLIANCES

ABSTRACTS

13-14 FEB. • TAJ MANSINGH • NEW DELHI

Eco-refrigeration: global state of art

Observations on the Status of Hydrocarbon Technology in Domestic Refrigerator Markets
- Western Europe with Global Prospects -

Paper presented to the ECO-REFRIGERATION Conference, New Delhi, February 13-14, 1996

by Othmar Schwank, INFRAS and Stephan Sicars, FKW

Abstract

The paper reviews the factors governing the introduction of Hydrocarbons as refrigerants and foam blowing agents in Western Europe during the period 1992-1995. It assesses the influence of the accelerated CFC phase out policy by the European Union, of consumer preferences and of the technical rationale which made isobutane (as refrigerant) and cyclopentane (as foam blowing agent) preferred technical options for Hydrocarbon refrigerators supplied to Western European markets. While on this market of 350 mio. people cyclopentane had reached a market share of close to 100% in 1995, about 25% of the refrigerators were sold with isobutane as refrigerant.

The share of isobutane in domestic refrigerators is rapidly increasing. The global coverage of Hydrocarbon compressors for domestic and commercial purposes had reached some 6% in 1995 as compared to 35-40% of HFC134a. Technical, economic and ecological considerations suggest that Hydrocarbons would be a preferable technical option to convert the remaining half of CFC12 compressor production. Further evidence resulting from the co-founding factors shaping the preference given to isobutane on the European market is presented, which suggests that besides isobutane also Hydrocarbon blends should be reevaluated for an accelerated global conversion strategy.

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ENERGY-SAVING DESIGN OF NO-POLLUTION REFRIGERATORS

Application of CHs on the Refrigerators made by
Haier Group Qingdao, China
Written by He Chuanqiao Wang Dongning Dong Changwel Lu Zhikun

Abstract

The following article introduces the work done by Haier Group on the CFC substitution, mainly experiences obtained from using CHs as foaming agent and refrigerant. It also describes changes of performances of refrigerators after being subjected to foaming agent of cyclopentane and refrigerant of isobutane, especially the realization of "zero pollution" to environment and super energy-saving. All these prove that CHs is a potential suitable CFCs substitute in the field of refrigeration.

ECO-REFRIGERATION: AN OVERVIEW OF HYDROCARBON TECHNOLOGY IN INDIA

Dr. R S Agarwal
Mechanical Engineering Department, Indian Institute of Technology, Delhi

Abstract

ECOFRIG project is an collaborative research project with the overall objective of the technology co-operation to assist Indian domestic and commercial refrigeration subsector in adaptive research, development and industrial application of ozone friendly energy efficient refrigeration technologies. The research Institutions such as Indian Institute of Technology, Delhi (IITD), National Chemical Laboratory, Pune (NCL) and Tata Energy Research Institute, Delhi (TERI) have been carrying out research and development on hydrocarbon technology for domestic and commercial refrigeration appliances in close co-operation with some of the domestic refrigerator manufacturers. This brief presentation highlights the studies carried out on the various aspects of hydrocarbon technology, such as design, development and evaluation of hydrocarbons as refrigerant, safety issues, standard & regulations during manufacture & use of hydrocarbon appliances and measurement of energy consumption in existing refrigerators under field & laboratory conditions.

CFC REPLACEMENTS: R600A R1344 PERFORMANCE, MANUFACTURING, COSTS FROM THE COMPRESSOR POINT OF VIEW

F. Rozza
Necchi Compressori, Italy

Abstract

Although the CFC phase out has already been decided and since some years all over the world many manufacturers have been working on this, the final solution accepted globally has not been identified yet.

Furthermore, many countries who have not yet operatively implemented any non CFC solution are evaluating some alternatives.

In this paper, starting from the physical data related to the different solutions, some considerations will be done taking into account design, manufacturing consequences and possible related costs. The point of view will be the compressor manufacturing.

Also some considerations will be done on retrofitting the existing CFC refrigerators when this gas will be no more available.

HFC R134a AND HYDROCARBON APPLIANCES IN DOMESTIC REFRIGERATION: MARKET TRENDS, CONVERSION

Juergen Melzer
Liebherr, Germany

Abstract

The phase out of CFC's and HFC's in domestic refrigeration is one of the biggest challenge that the refrigerator industry had to face in the last decade. Confronted with quite tough deadlines set by the Montreal Protocol and the respective governments, the industry especially in Germany undertook immense efforts to find suitable solutions.

The search went for final solutions with ODP=O and GWP nearly O, that would require to convert a factory only once, not twice.

In the foam sector the final solution had been found with C-Pentane, introduced in 1993 by the whole German industry. Until today the worldwide acceptance of C-Pentane is great with only some major countries like USA, Brazil staying apart, R141b and R134a are not more regarded as viable alternatives.

The situation for the refrigerants is not so clear:
In 1992/93 R134a seemed to be the only viable alternative. But then the hydrocarbon alternative was launched - again by Germany - first as blend and then as the pure Isobutane R600a. In Europe this will be the long term solution with growing market shares, that reaches 90% in Germany and up to 50% in the European Union.

For a lot of other countries this problem is closely linked to compressor manufacturing and therefore the decision is more difficult.

The safety aspects of both HC's can be regarded as completely solved and need only the required careful handling.

THE USE OF SYNTHETIC AND NATURAL FLUIDS IN COMMERCIAL REFRIGERATION APPLICATIONS

Dipl.-Ing S. Sicars
FKW GmbH - Research Centre for Refrigeration and Heat Pumps Ltd
Hannover, Germany

Abstract

Refrigeration technology plays an important role for safety and health of the world's population Especially the preservation of food is vital for the stability and economic growth all over the world. Refrigeration technology provides the technical aids to chill food following the cold chain without any interruption, starting at production, coming to transportation, finally storage, sale and storage at the consumer's home in a refrigerator

Other applications include air-conditioning systems improving the comfort of human beings in private as well as for commercial purposes and also industrial processes where refrigeration is used e g for recovery of expensive or environmentally unacceptable substances

This paper highlights the refrigeration technology options based on natural fluids newly redeveloped in Europe as compared to technology options based on continued use of still halogenated substitutes for CFCs, such as CFC-12 and CFC-502. Cost effective natural fluid based technical options in commercial refrigeration applications and in air conditioning .have been launched on the market or will become available in the near future. This paper will also discuss present changes in the sectors of heat pumps and air conditioning systems due to the fact that those and commercial applications often have similar or equal components and a similar layout

For phasing out CFC-12, HFC-134a, which has a vapour pressure curve very similar to CFC-12 is proposed as replacement by its producers. Similar to HFC-134a, several HFC mixtures were developed to replace CFC-502 and, later on, HCFC-22. These fluorinated substances do not damage the ozone layer, but have still very significant greenhouse warming effects Severe disadvantages of these fluids in connection with their refrigeration oils and substances remaining from the production process are evident.

Natural fluid technology presently available offers similar, often higher performance than achieved with today's refrigerants, while at the same time continuing to use the same oils, components, elastomers and production processes like CFCs This technology is the safe use of hydrocarbons for refrigerators, small commercial and air-conditioning equipment, while for larger air-conditioning systems and industrial uses ammonia is proposed.

Today hydrocarbons are already used in domestic refrigerators and increasingly in the field of commercial refrigeration, air conditioners and for heat pumps. It is expected that the field of applications will expand in the near future, especially for small compact units The flammability of hydrocarbons has to be considered for production and lifetime of the appliance To ensure safe operation, some design changes have to be incorporated in the design

The use of hydrocarbons in household refrigeration caused also manufacturers of other refrigeration applications to consider those refrigerants. While several small enterprises started soon after the refrigerator industry to promote hydrocarbon systems, e.g. for beer cooling, the first major use of hydrocarbons in refrigeration applications was the use of heat pumps, produced on an industrial scale. Since mid of 1994, heat pumps with hydrocarbons are available on the market in a large scale.

The main technical difference to refrigerators is the amount of filling, which is up to 2 kg of HC-290. In this year, the market share of the hydrocarbon heat pumps for space heating is close to 100% in Germany, a market with approximately 1500 space heating heat pumps per year. The largest European producer of mobile room air-conditioners, DeLonghi, and the German AEG introduced small hydrocarbon

air conditioner product lines in summer 1995. For applications with more than around 50 kW cooling capacity an alternative for the use of CFCs is the increased use of ammonia.

The general know how concerning construction, servicing and operating of ammonia equipment is available world-wide. New technologies allow to use ammonia with techniques similar to those used with CFCs, improving the cost effectiveness also of small ammonia plants to the level achieved with HFCs or, in case of larger equipment, even further. Typical new applications of ammonia as working fluid are supermarket applications and centralised air-conditioning systems. In case of the supermarket systems, the necessary development of suitable brine systems to distribute secondary refrigerants slowed down the development. On the other hand, the use of ammonia in air-conditioning systems is now a widespread technology.

Presently, the market share of large air-conditioning systems with ammonia is reported to be close to 100% in Sweden and Luxembourg and around 30% in Germany and Switzerland. In general, the ammonia market for air conditioning is well developed in Middle and North Europe. In the Southern countries of Western Europe as well as in Great Britain and France so far only small market shares of ammonia plants in large air-conditioning systems have been achieved.

Natural refrigerants in general and hydrocarbons in particular are suitable for refrigeration purposes in industrialised as well as in developing countries. The safety issues, which have to be considered, can be solved with technology and know how available for decades The refrigerants are cheap and accessible, the know how for their handling is available. Natural fluids have proven to perform similar or better than any other alternative in a refrigeration cycle. The technology to be used is proven Several manufacturers selected this technology for their large scale production Among those are subsidiaries of the world's leading refrigeration companies.

On the other hand. The other alternative for the use of CFCs are HFCs For the use of CFC-502 and HCFC-22, there is no really convincing long term HFC solution available yet. This technology requires a high level of organisation in production and service.
Even if the required quality in the production processes can be achieved in the factories in developing countries, a sufficient level of quality in the manufacturing of the various component suppliers is doubtful, whereas it is certain that the unorganised service sector will not be able to fulfil all the requirements of proper operation.

Thus, it seems to be very worthwhile to consider natural fluids in general and hydrocarbons for refrigerators and small hermetic applications in particular as an alternative option to the HFC technology.

HYDROCARBON REFRIGERANTS: PROPERTIES, PURITY AND SAFE HANDLING

Jane Gartshore
Cool Concerns, UK

Abstract

This paper outlines the range of hydrocarbon refrigerants available (single substances and blends) and shows how they can be safely applied and handled.

The hydrocarbons examined are those in the Calor Care range. These are pure isobutane (Care 10, R600a), pure propane (Care 40, R290), Care 30 (propane/isobutane blend) and Care 50 (propane/ethane blend). These refrigerants can be used in new systems and to replace CFCs, HCFCs and HFCs in existing systems. They are all nontoxic and are compatible with all common refrigeration system materials.

It is important that the correct hydrocarbon of a very high purity is used in a refrigeration system. Using commercial grade liquified petroleum gas (LPG) as an refrigerant will result in a system operating at unpredictable conditions, with an unpredictable performance. Some components of the LPG will contaminate the system, with the risk of premature compressor failure.

Care 10 has a lower capacity than R12 and a similar efficiency. It can only be used with special designed compressors. Care 30 has the same capacity as R12 and better efficiency. It can be used with compressors and systems designed for R12 - the system will cost less to run.

Care 40 has a lower capacity than R22 and a different efficiency. It may need a larger compressor. Care 50 has the same capacity as R22 and better efficiency. It can be used in systems designed for R22 (or R502) and the system will cost less to run.

The hydrocarbon refrigerants are flammable. For combustion a concentration of between 2% and 10% of refrigerant in air is needed, as well as an ignition source. Naked flames are ignition sources. There may be enough energy in a spark from an electrical component to provide ignition. For the safe application of hydrocarbons in systems where the refrigerant could leak into an enclosed space the following precautions should be taken:

- limit the charge quantity so that a leakage will not result in a potentially flammable mixture of air and refrigerant in an enclosed space;
- eliminate ignition sources in the enclosed space;
- use permanent atmosphere monitoring in the enclosed space to sense a dangerous level of refrigerant in the air.

Charging equipment for hydrocarbons should be intrinsically safe (i.e. there should be no ignition sources). There should also be no ignition sources in the charging area.

Hydrocarbon refrigerants should be stored transported according to local regulations.

PROPERTIES OF CYCLOPENTANE BLOWN FOAM

Mike Jeffs
ICI, Belgium

Abstract

The international and national policies to phaseout CFCs and, eventually, HCFCs posed a major problem for the manufacturers of domestic refrigerators and freezers who rely on polyurethane rigid foam for insulation, strength and production efficiency.

There has been a five year period of uncertainty during which many replacement blowing agent options have been evaluated. Several HCFCs have been extensively evaluated and some, notably HCFC 141b, are in use. However, cyclopentane was introduced in German refrigerator factories in 1993 and has since become the dominant blowing agent in Europe and its use is spreading rapidly to both developed and developing countries worldwide. This acceptance is based on its environmental properties of zero ODP and very low GWP which offer the manufacturers of appliances a period of stability. The technology offers a one step change to a durable solution and where developing country enterprises can learn from the experience of those in developed countries.

This paper describes the properties of cyclopentane-based foams in comparison with CFC 11 and with the other options. It also indicates that precautions must be taken because of the flammability of cyclopentane. These precautions are described in details in an accompanying paper.

Despite these precautions and the accompanying equipment modifications, it is clear that cyclopentane offers a cost effective solution. One of the main reasons for this is that the resulting foam is compatible with the plastic liner materials developed for use with CFC 11.

It will also be made clear that the technology is still evolving and there will be improvements in the properties of cyclopentane-based foams and refinements in the composition of the blowing agent itself. The application of vacuum panels and the potential use of liquid HFCs will also be discussed

MANUFACTURING EQUIPMENT FOR PENTANE-BLOWN FOAM FOR REFRIGERATORS

Massimo Castiglioni
Afros Cannon, Italy

Abstract

Cyclopentane is now accepted and widely used as the expanding agent replacement for CFC11 in rigid Polyurethane foams for insulation applications. Today it is mainly utilised in domestic and commercial refrigerators and freezers.

Cyclopentane-blown foams would seem to represent the transition solution - for this application for the next decade.

The conversion of existing plants and the installation of new, dedicated ones has interested all the major groups present in Western Europe, as well as those who manufacture in the former USSR, in Poland, Hungary and the Czech and Slovakian Republics. By the end of 1995 all the current European manufacturers will have started their production using cyclopentane as blowing agent. North America still does not use Cyclopentane, preferring HCFC141b.

The major South American manufacturers have specified all their new plants for using Cyclopentane. In Australia and New Zealand the market is shared amongst a few major suppliers and we observed two or three factories already in production with Cyclopentane.

Asia: Japan does not seem to be the right country for this explosive blowing agent. Cyclopentane have been supplied, as well as some manufacturing lines for small production runs.

China and India are moving towards Cyclopentane using multi-lateral funds help: a number of new dedicated plants have been ordered recently.

All south Korean producers will have some Cyclopentane capable lines in production by 1995. In Thailand one plant was ordered and should be in operation by now. In Malaysia and Indonesia negotiations are currently held under UNDP supervision.

As a matter of fact, the successful installation of more than 100 plants from our group only has confirmed the following provisions:

- The safety measures recommended from the very beginning of this technology were proper and correct.
- The consistency of the process is proven.
- Foam's performances are improving: compared with the early formulations significant steps forward have been achieved in flow, insulation factor, dimensional stability, moulded density, demoulding time.

New Technological Requirements

The introduction of Cyclopentane in Polyurethane foams has obviously meant some changes in the manufacture of refrigerators. Equipment for storing and premixing Cyclopentane had to be added, metering equipment and foaming fixtures had to be adapted or replaced. Four basic scenario characterise this industry:

- manufacturers of domestic refrigerators and freezers working with a limited number of models in large batches;

Contd...2

- manufacturers of small-medium batches of refrigerators;
- manufacturers of very large refrigerators and freezers for commercial applications;
- producers of panels for cold rooms and walk-in coolers.

Cannon Solutions Available

Each of these cases requires a specific approach and has a different technical solution. Cannon have supplied up until now more than 100 different solutions to 60 different customers in the World.

Several products are available:

1) **Pentane Storage Stations**, above ground or underground
2) **Multi-Easy Froth**^{TM} a high-pressure pre-blending unit able to prepare mixtures of Polyol and Cyclopentane of LBBA.
3) **Penta-Easy Froth**^{TM} a high-pressure pre-blending unit specifically designed for Cyclopentane.
4) **Pentamodule,** a complete kit dedicated to the Polyol side of an existing foaming machine.
5) **"A-System Penta,"** a complete high-pressure metering machine containing an integrated Polyol-Cyclopentane blending unit under the same suction hood.
6) **Injection Area**, for the injection and polymerisation area retrofitting solutions for existing plants and totally new ones have been supplied.

CONCEPTS AND EXPERIENCES IN SERVICING OF REFRIGERATION APPLIANCES (MAINLY ISOBUTANE/R600a)

Juergen Melzer
Liebherr, Germany

Abstract

Due to market constraints in Germany and Europe, LIEBHERR had to start in 1993 with R134a to replace R12.

Consequently the service equipment had to be changed, using vacuum pumps with Estheroil.

In the field we faced a higher repair rate compared with R12, due to several factors, but mainly due to the higher sensitivity of HFC134a against humidity (a problem more important in India than in Europe).

At LIEBHERR we changed consequently from R134a to R600a since 1993 and have now a relation of about 80/20 in favour of R600a.

A new appropriate service concept had to be found and was designed by LIEBHERR in 1993.

Later on it was accepted and taken over by most other manufacturers.

The whole procedure is simple and safe, which is proved by the fact that not a single accident occurred since its introduction in 1993.

TRAINING NEEDS FOR SERVICING OF REFRIGERATION APPLIANCES

Jack Buswell
Calor Gas Refrigeration, Calor Gas Limited, Appleton park, UK

Abstract

This session is a supplement to that entitled, "Hydrocarbon Refrigerants: Properties, Printing and Safe Handling", which covers the content of the training for serviceperson.

The Training Needs analysis for serviceperson in the Indian RAC industry needs to examine the operational methods currently adopted; what is the base knowledge, skills and equipment (resources) deployed, and what organisational adjustments may need adjustment to provide controls for safety

European Training Experience will be useful for the safe application of CARE refrigerants in India However, the design of the total training programmes must obviously be specific to local environments, methods, language, regulatory framework and culture.

ECO-REFRIGERATION

CONFERENCE ON HYDROCARBON FLUIDS IN DOMESTIC AND COMMERCIAL REFRIGERATION APPLIANCES

PAPERS

13-14 FEB. • TAJ MANSINGH • NEW DELHI

ECO-REFRIGERATION: GLOBAL STATE OF ART

DR OTHMAR SCHWANK
INFRAS, SWITZERLAND

ECOREFRIGERATION
CONFERENCE ON HYDROCARBON FLUIDS IN DOMESTIC
AND COMMERCIAL REFRIGERATION APPLIANCES

Observations on the Status of Hydrocarbon Technology in Domestic Refrigerator Markets

- Western Europe with Global Prospects -

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by Othmar Schwank, INFRAS and Stephan Sicars, FKW

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1 Hydrocarbon Refrigerants

1.1 Background - The Hydrocarbon Story in short

Prior to the discovery of the CFCs, Hydrocarbons have been widely used as refrigerants in domestic and commercial refrigeration. They had been gradually replaced due to the advantages of the non-flamable nature of CFCs.

The revival of the Hydrocarbon technology in Europe during the early 1990ies is likely to turn out as an interesting piece of technology history. The high global warming potential and the incompatibility with mineral oils of HFC134a - promoted as the mainstream replacement for CFC12 in domestic refrigeration - made first researchers, then industrial manufacturers of refrigerant equipment look into the group of so-called natural fluids as refrigerant alternatives to CFC12. So Hydrocarbon refrigerants, requiring only well known technology with respect to the refrigeration cycle, were reconsidered. For safety related design changes prooven technology from petrochemical appliances were available. Different tests with Hydrocarbon refrigerant were made in the late 1980ies, no manufacturer was however prepared to announce a Hydrocarbon based domestic refrigerator until 1992.

In 1992 - the year of the Rio Conference - the Copenhagen Amendment advanced the CFC phase out date to 1.1.1996 for article 2 countries. The European Union had already prior to Copenhagen announced to phase out CFCs by 1.1.1995 while Germany's manufacturers volunteered for an earlier date (mid-1994). Manufacturers were put under strain to come out with green refrigerators by 1993. In 1992 Greenpeace - with an effective media campaign and a R&D contribution of DM 30'000 - supported the East-German manufacturer Foron with respect to the development of the first modern Hydrocarbon refrigerator based on a Propane/isobutane blend. The announcement of this technology forced more and larger refrigerator manufacturers to proof their ability to develop similar models.

The media presence and sale success of the Foron refrigerator, backed up by an environment price award and the environment label „Blue Angel", did in 1993 also move up the CFC/HFC-free products put into market by the other two German Hydrocarbon pioneers Liebherr and Bosch-Siemens. These two manufacturers launched the first isobutane/cyclopentane refrigerators

In order to meet the 1994/1995 CFC phase out dates - these companies as well as the players associated to the Whirlpool Group (Bauknecht) and the Electrolux Group (AEG) had to convert the bulk of their models to HFC134a - an R&D work that was completed to approximately 50% by fall 1992. Then the landmark decision in favor of Hydrocarbons had been taken within Germany's refrigerator manufacturer's association - a decision to which the German Environment Ministry significantly contributed by questioning the rationale behind the „HFC134a only" position so far taken by the manufacturer's association. FORON was the only manufacturer present on the German market who did not first convert to HFC134a. Informally, Liebherr and Bosch-Siemens confirm that they never since have regretted the landmark decision of fall 1992 facilitated by them, since, thanks to the R&D masterpiece launching isobutane refrigerator models within 6 months time only, they ultimately will got rid of the HFC134a related problems experienced by them in-between 1992 and 1994.

1.2 Rationale Isobutane vs. Hydrocarbon Blends

For taking the lead in conversion to Hydrocarbon refrigerants Foron benefitted from the strategic advantage of still producing its own compressors. This put Foron into a position to launch a simple conversion solution. Foron's conversion criteria were: safe product and at least CFC12 equivalent performance at minimal conversion cost for compressor and refrigerator design adjustment. The conversion to a blend of propane (HC290) and isobutane (HC600a) matched the cooling capacity of CFC12 with a given compressor displacement almost exactly. Thus any major conversion of compressor production was avoided.

The Hydrocarbon blend as compared to CFC12 does have - besides flamability - some demerits such as slightly higher noise level, the problem of temperature glide and the possibility of a differential leakage. Compared to blends the major merits of HC600a being a single refrigerant are its higher energetic efficiency and lower noise emission levels The major players on the German market accordingly gave preference to HC600a.

Hydrocarbon blend compressors fulfilling the same requirements of high energetic efficiency and lower noise emission levels could not be developed within the short 6 months time span in between the landmark decision in favor of Hydrocarbon refrigerant and the market introduction of the Foron refrigerator. The first Hydrocarbon compressors freely accessible on the market were HC600a compressors produced by Danfoss. The warranty for this compressor was granted later on only. The extremly fast growing market for isobutane refrigerators took some big players in the compressor business by surprise. They had invested heavily in HFC134a conversion and were not prepared for an almost simultaneous second conversion to Hydrocarbons. So, the limited supply of compressors together with the above mentioned isobutane merits made the preliminary selection of HC600a an acknowledged standard.

1.3 Development of Market Shares: HC Compressors

By 1994/1995 the European factories of Electrolux, Zanussi, Unidad Hermetica and Verdichter Oe, had joined producing HC600a compressors on a large scale. The European subsidiary of Embraco Brazil, which in turn belongs to the Whirlpool group, has been catering a sizeable portion of the growing Western European HC600a compressor market. Matsushita, after loosing some of the previous HFC134a market share, had introduced an own HC600a line for the European market. Americold, being a subsidiary of Electrolux group, is the only North American compressor manufacturer known to have launched at least a HC600a prototype production. Independent Western European compressor manufacturers are Danfoss in Denmark, Necchi in Italy, and Foron, all of them manufacturing large amounts of Hydrocarbon compressors. Danfoss is estimated to be the leading manufacturer with approximately 2 5 mio compressors sold in 1995 The total market volume of HC600a compressors in Western Europe is estimated at 4 to 5 mio units for 1995. The share of isobutane compressors within the domestic refrigerator market is rapidly increasing. The market of small plug-in commercial appliances started to grow for isobutane compressors recently The global market share of isobutane compressors may in 1995 have reached 6% of a total volume of estimated 70 to 80 mio compressors (as compared to some 35 to 40% of HFC134a compressors) The experiences gained from the European market, where manufacturers had the chance to test both the technical options HFC134a and Hydrocarbons on a large scale, suggests that Hydrocarbons would be a preferable option to convert the remaining half of CFC12 compressor production. Technical, economic and ecological evidence does support this conclusion (FKW/INFRAS 1996).

Since the purchasing power of the global markets to be converted yet from CFC12 to a non ODS is lower and so is the cleanliness of the industrial manufacturing as well as servicing conditions, the considerations which made Foron choose Hydrocarbon blends initially may have to be reevaluated. Also Foron had operated within lower purchasing power segments of the German market. Taking into considerations such experiences from the Italian market Necchi has developed a parallel line of Hydrocarbon blend compressors showing good results (BISCALDI 1996).

1.4 Development of Refrigerator Market Shares in Western Europe

The introduction of Hydrocarbon refrigerators has been consumer driven. Big warehouse groups had taken the lead in that process on the German market. Since Germany - in particular after reunification - is the most important market in Western Europe, other European suppliers had to launch Hydrocarbon refrigerator production as well. Due to the above mentioned short supply of Hydrocarbon compressors, much advanced CFC phase out dates (1.1.1994) in some countries such as Sweden and Switzerland and restricted national safety regulations in the United Kingdom and the Netherlands for instance, most Western European countries converted to HFC134a first Outside Germany sales of Hydrocarbon refrigerators started to pick up sizeable amounts in course of 1995 only. Therefore the present market share of Hydrocarbon refrigerators in Western Europe is approximately 25% (Figure 1).

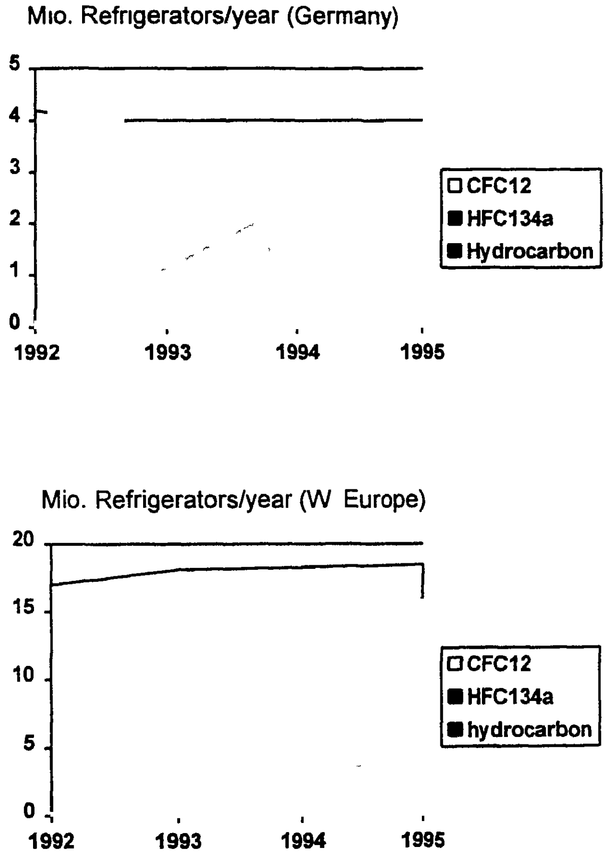

Figure 1: Refrigerator market and market share of hydrocarbon refrigerators in Germany and Western Europe between 1992 and 1995 (estimate, source FKW/INFRAS 1996)

The refrigerator demand on the German market reached a peak 1990/1992 after the reunification. Upto 1995 the German market had pulled up the sales figures of

Hydrocarbon refrigerators. Within 1995 safety regulation were gradually egalized within the European Union (British Standard 4434, DIN 7003, etc) and had been formalized in an international standard as well. These standards have become the guideline for these manufacturers which had not converted to Hydrocarbon yet. These standards and increasing demand for safety components have allowed to reduce the production cost of Hydrocarbon refrigerators compared to the pioneer conversions of 1993. Production cost of Hydrocarbon refrigerators do range in between the CFC12 and HFC134a technical option. The sales trends for Hydrocarbon refrigerators past 1995 will be set by comparative performance, service network and marketing strategies adopted on the markets in other European contries than Germany Preliminary observations made during 1995 indicate that the demand for Hydrocarbon refrigerators does pick up faster in the European countries North of the border separating the roman and german based language groups (Table 1). This observation is related to a cultural difference which also is reflected e.g. in different approaches to product liability legislation or a higher willingness to pay for conservation of natural resources among the population of Northern Europe. It is related to the different valuations given to common property within the historical German and roman legal systems.

Region	**Refrigerant**	**1993**	**1995**	**1997 (forecast)**
Northern West Europe	CFC12	40%	10%	0%
(Ir, GB, NL, L, G, S, N,	HFC134a	40%	50%	20%
DK, CH, A)	HC600a	20%	40%	80%
total no. of units		10 mio	10 mio	10 mio
Southern West Europe	CFC12	60%	15%	0%
(B, F, I, E, P, H)	HFC134a	30%	75%	60-70%
	HC600a	0%	10%	30-40%
total no of units		9 mio	9 mio	9 mio

Table 1: Domestic refrigerator sales trends in Western Europe by refrigerant (CFC12, HFC134a, HC600a), estimate INFRAS based on personal communication with marketing departments of refrigerator manufacturers.

2 Foam

The European manufacturers had reduced the ODS use in foam blowing in several steps. In a first step the content of CFC11 in the foam was reduced from 120g/kg foam, being the Western European practice upto 1990/91 to around 60g CFC11/kg foam This change was carried out until 1993

The next step considered was to completely phase out CFC11 using HFC134a or HCFC141b as substitute blowing agent. This conversion strategy was yet in a stage of internal evaluation in mid-1992 when the Copenhagen Amendment of the Montreal Protocol to advance CFC phase out date in article 2 countries by 1.1.1996 took shape (personal communication with Rolf Segerström of Electrolux in Zürich, July 1992). In course of 1992 the majority of the manufacturers catering to the German market decided to convert their foaming processes to HFC134a. The HCFC141b technology favored by US manufacturers was not seriously considered in Europe due to the needed second conversion around 2000. This technology was neither prooven in 1992. Those manufacturers which converted to HFC134a used it only for a short time as foam blowing agent. The landmark decision within Germany's manufacturer's association to accept a flamable refrigerant, turned the scene in fall 1992 also in favor of cyclopentane as foam blowing agent. Liebherr and Bosch-Siemens converted their foaming lines to cyclopentane in spring 1993. The other German manufacturers then gradually reconverted from HFC134a to cyclopentane as well. Most of the European manufacturers which had to meet the EU conversion date of 1.1.1995 achieved a market share of close to 100% within Western Europe (Figure 2).

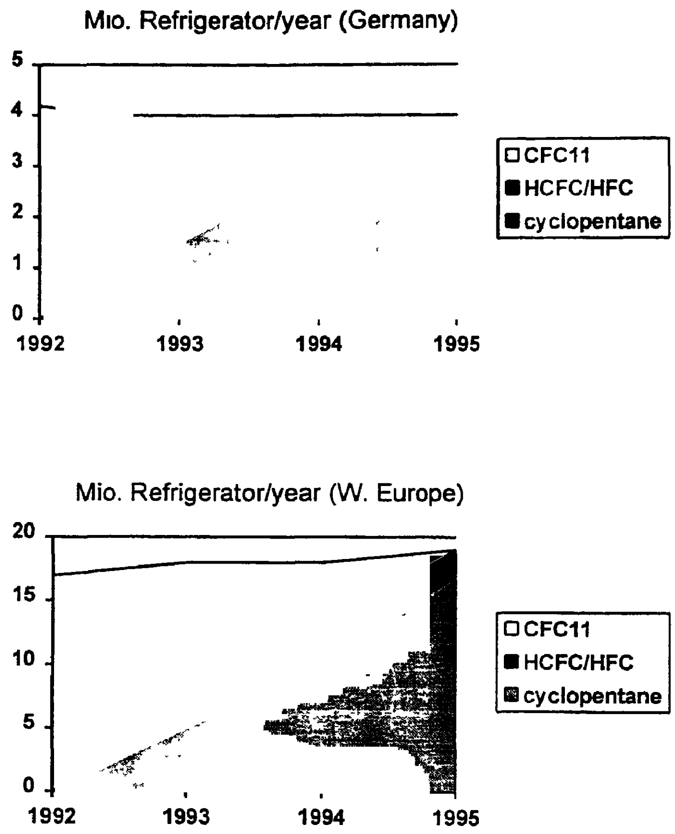

Figure 2. Refrigerator foam blowing agent market shares (CFC11, HFC/HCFC, cyclopentane) in Germany and Western Europe between 1992 and 1995

In Western Europe preference as foam blowing agent was given to cyclopentane due to the following technical and non-technical considerations

- Negligible global warming potential (GWP) compared to HFC134a,
- Zero ozone depletion potential (ODP), no second conversion past 2000 as needed if HFCF141b would have been choosen. This technology was not proven yet in 1992,
- Accelerated CFC phase out schedule adopted by the European Union made a technology decision mandatory in late 1992

3 Conclusions

The market introduction of the Hydrocarbon technology for domestic refrigerators succeeded in Western Europe mainly due to the following non-technical and technical co-founding factors.

- The advanced phase out schedule of the European Union for CFCs hat put manufactureres under time pressure to decide technical options ahead of time as compared to US or Japanes manufacturers. Secondly the EU had also regulated the use of HCFCs in new appliances These policy shaped the choice of cyclopentane as foam blowing agent.
- The adoption of cyclopentane was facilitated since R&D departments of German manufacturers had in fall 1992 acknowledged the strategic advantages of converting to Hydrocarbon refrigerant - for technical rationale. Accepting a flamable fluid in foam blowing and as refrigerant had facilitated each other
- The presence of a large group of consumers with a willingness to pay for a green refrigerator. The demand for an ecologically sound product turned out to be strong enough to make many refrigerator manufacturers to convert the refrigerant within one to three years twice: First from CFC12 to HFC134a and second from HFC134a to HC600a.
- After establishment the Hydrocarbon technology on the market the technical rationale will gradually lead to complete replacement of HFC134a by Hydrocarbons. This process has started to spread to commercial appliances.

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ECO-REFRIGERATION: HIGHLIGHTS FROM CHINA

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ECOREFRIGERATION
CONFERENCE ON HYDROCARBON FLUIDS IN DOMESTIC
AND COMMERCIAL REFRIGERATION APPLIANCES

Dr. Klaus Meyersen
Advisor and Coordinator to GTZ CFC-Phase-Out-Projects

A Personal Opinion:
THE TWELVE ADVANTAGES OF HYDROCARBON TECHNOLOGY

Opportunities for Article-5-Countries
Approved by the Multilateral Fund
Developed in Germany
Supported by GTZ

Monday, February 5th. 1996

Preface

My considerations deal mainly with the use of hydrocarbons as refrigerants (isobutane, blends of propane/butane), since I experience that this application of hydrocarbons rises most of the questions. Cyclopentane as the foaming agent I see already firmly established as the world-standard foaming agent for the insulation of household appliances. It will therefore only be mentioned in passing.

I would like to point out that the aspects of hydrocarbon technology presented here and the views expressed on this technology vis-a-vis the Multilateral Fund of the Montreal Protocol are my personal opinion. Since I am frequently asked about various aspects of hydrocarbon technology and the present situation within the Multilateral Fund of the Montreal Protocol, I thought it might be useful to put my knowledge in writing, and thus to take advantage of my contacts on various levels of the Montreal scene to pass on this information. I express my view primarily as advisor to the Federal German Agency for Technical Co-operation (GTZ), which promotes hydrocarbon technology, but I also try to convey my observations from and to many MFmeetings and committees - such as the Executive Committee, the OORG etc. - dealing with this technology.

On the one hand, the introduction of hydrocarbon technology in the domestic refrigeration industry has gained astonishing momentum in recent months. On the other hand, large political and administrative bodies, such as the Montreal Protocol, are so slow in facilitating information flow to the "executive level" (by which I mean the level of the people actually using it!). So I hope - by using my semi-official contacts - to help accelerate the information flow within the wider scope of the Multilateral Fund and GEF up to the speed at which this new technology is gaining ground, so that the "executive level" in article-5-countries and other countries which would like to convert, has a chance to be informed quickly and thus to consider this technology as early as possible.

My opinion:

The Hydrocarbon Technology offers advantages on all three levels,

- the global level,
- the national level,
- the enterprise level.

The Aspects:

1

The most important aspect in introducing this technology is on the global level

No Further Contribution to Global Warming

The starting point 1990 for the unbelievably rapid development of this technology in Germany and Europe was Greenpeaces position that only the most environmentally friendly technology - hydrocarbons - should be used, since 134a still has a factor 1200 over the carbon dioxide standard So it may indeed only be a minor contribution to global warming in total, compared to other carbondioxide emission sources, it stays a signal for a better ecological solution that became available as with the hydrocarbons. Unfortunately the Montreal Protocol is bound to support only the ozone protection in a narrow sense, hence will not pay for the additional positive effect this technology has on global warming. However, this advantage is well recognised in all bodies, the Multilateral Fund as well as in all of the Implementing Agencies and is getting their support. Although the regulations do not allow extra payment, in a way this global warming contribution is acknowledged in exchange for the extra costs on safety in so far, as the costs for safety are not taken into account when compared to other technologies, but will be paid for to a certain degree.

2

The most promising facts about hydrocarbon technology however are on the enterprise level.

The Technical Advantages will be the (!) Driving Force

There are likely more than 5 million refrigerators already produced in Germany, Europe and now also in China, without any reported accident during daily use. Although it was the ecological advantages that got hydrocarbons off the ground in the first place, today it is clearly the other advantages in regard to production and daily use which are emerging and are seen clearly now These are hard economic facts that will interest the industry. I am convinced that these facts will be the future driving force for hydrocarbon technology worldwide. Facts like energy-saving, "whispering" refrigerators, readily available materials, savings in compressor design, virtually no refrigerant losses in production, extraordinary reliability of the cooling system, no fees on licences and patents, as well as the assurance that no second conversion will be charged on the enterprises in later years, these facts will interest any manufacturer worldwide And that will keep this technology moving on.

3

Not fully addressed yet is the advantage on the national level:

The National Advantage of Know-How Independence

In the past this technology started with the ecological merits (Greenpeace; no global warming) which convinced the greens everywhere. Last year the economical advantages became obvious, which will eventually impress the industry everywhere in the world. However this technology needs a further push. Now. The most political argument I find still missing so far in worldwide argumentation, in particular with all the queries going on about know-how supply: the Hydrocarbon Technology leads to independence from Western / Northern know-how (no patents, no licenses)! This is an issue for each company but also for the highest political level in each country, in particular in China, India, and this will also apply to Russia and other states being supported by the GEF. Governments seem to have for too long allowed themselves to stay "neutral" in the economically based strive for "chemistry base technologies". However, these technologies, hydrocarbon and ammonia, support any governments and companies in their attempts to lessen dependence. This technology offers the chance to adapt national "natural" solutions. Instead of being fixed to this little financial support the MF can render, instead of arguing at length about the money getting more scarce and about the everchanging rules and regulations which are therefore are getting tighter, just go ahead and do it! In this public money game everybody seems to make fools of themselves in the long run. These large article-5-countries do have the means, should and could (!) easily pull their policy, people and other resources together and do it! By now it is proven to be simple, everybody can do it. The everongoing attempts by the North to keep control and make profits are perfectly matched in this psychology game by the other side due to lack of political awareness and determination in up-to-now know-how "dependent" countries. This to me looks an "old" attitude, a basic reluctance to really take on responsibility for one's own problems. Afterall, everybody (!) is using the comfort of cooling, increasingly so after 1987, the year of the MP! So, to me it seems time has come for all of us to grow out of this behaviour of the past and start with new thinking. Germany and Switzerland, I am certain, would be willing to assist further in any move for self-help.

4

The 12 Advantages in detail as I see them today (there may be many more!):

Advantage 1

No ozone-Depletion

No ozone-depleting effect as is the prerequisite of all other cfc-substitutes.

Advantage 2

No Global Warming

No globalwarming effect was the starting point of the whole hydrocarbon movement

Advantage 3

No Second Conversion

No second conversion - such as the one hanging over all halogen compounds (e.g. 134a) - in the long run 134a still contains halogens; fluorine instead of chlorine. The use of fluorine gives me, as a chemist, a more than uneasy feeling, since it is one of the most reactive of all elements and forms the strongest acid known. Even if all living scientists were to swear that it doesn't harm the atmosphere, I would feel better if we do not shoot it up there. After all, yesterday's solutions often seem to create today's problems - as did CFC's

Advantage 4

Energy saving

There is an energy-saving effect with an optimised refrigeration system of up to 10% over CRCs and 134a. This means a further lifelong contribution not to accelerate global warming - already a serious selling point in Europe with the newly introduced, compulsory energy labelling.

Advantage 5

Quiet Refrigerators

The physical properties of isobutane hydrocarbon refrigerators make for quiet, "whispering" refrigerators - an additional marketing aspect in Europe.

Advantage 6

Hydrocarbons readily available

The hydrocarbons cyclopentane and isobutane will probably (contrary to e.g. 134a) be readily available in most Article-5 countries and other self-relying countries as soon as there is a certain market for them, since they involve no synthetic chemistry, just purification. A realistic approach on purity demands (presently 98% pure; 99% was sought a year ago; future ??%) will further ease the situation.

Advantage 7

New Compressors self-made

For companies with their own line of compressor manufacturing, this technology offers at least a possibility - and in most cases it is a real chance - for them to develop new compressors for isobutane or a propane/butane-mixture on their own, at relatively low cost, out of their old CFC-compressor modules, whereas 134a definitely requires a completely new design With conversion to hydrocarbon there is in some cases a slight gain, in most cases equal level in energy consumption compared to CFC.

Advantage 8

Extraordinary Reliability

The most convincing argument, however, is the reliability of this system, which is bound to have fewer compressor failures. The close chemical connection between isobutane and mineral oil, which are both hydrocarbons, means that there is no interfering chemical interaction, which in the case of CFC- and FC-compounds leads sooner or later to corrosion and hence to compressor failure, mostly due to moisture from high humidity But hydrocarbon compressors run "forever": test runs show that 4 million hours can be conservatively expected (80,000 hours - 15 years - is the current desired standard and the average lifetime of refrigerators so far). This high reliability feature was probably the main reason why German industry, impatient with the problems caused by hygroscopic 134a-oils, converted twice within two years despite the double costs of conversion.This sensitivity towards humidity is, of course, greatly increased in the tropical or subtropical climates of most Article-5 countries This is why German manufacturers publicly expressed to the MF their concern that in these countries 134a will result in a high failure rate and recommended hydrocarbon technology for any company with a technical basis for conversion to hydrocarbons.

Advantage 9

Virtually no refrigerant losses

The only disadvantage of hydrocarbons is their flammability, which requires careful design and thorough employee and service sector training The European refrigerator industry shows that it can be done. After all, the world has learned to live with a similar open system with gas escaping freely: the cigarette lighter No one worries about people carrying three cigarette lighters - the flammability potential of a house-hold hydrocarbon refrigerator - in pockets or handbags, where they bounce around a lot more than a kitchen fridge does! Ironically I have the suspicion, that this only disadvantage is at the same time a further advantage. Looking at the ODS phase-out effects of hydrocarbons may result a considerable and additional contribution, although it is one of the hidden effects, more in the grey area of a guilty conscience, not openly spoken about since it is embarrassing, none I could find in any official document yet: Due to the danger of flammability these substances are naturally handled with utmost care This has the effect that there is virtually no "losses" in the manufacturing process. On the other hand manufacturers handling CFC's as well as 134a experience considerable losses in these technological processes; I am told that sometimes the amount purchased is 1 8 times bigger than that which finally leaves the factories in form of the manufactured goods, the rest - another 80%! -goes somewhere, likely due to the attitude, "it is harmless to me". This lead to the remark of one of the leading German manufacturers, that "the Hydrocarbon Technology forces us to work with this care we should always have worked with".

Advantage 10

No extra Servicing Equipment

The tenth advantage for using isobutane lays in the service sector and is another economical benefit There is no extra servicing equipment necessary for isobutane over CFC, whereas 134a requires a complete new system additionally

Further on servicing

Although in this paper I am dealing only with the industrial sector I should at least mention the service sector, since servicing hydrocarbons arises a lot of worries against this technology. Handling hydrocarbons in the service field can be as safe as CFC or 134a as far as the danger of accidents due to the flammability is concerned, the situation in Germany proves this. The use of hydrocarbons in the servicing sector offer another considerable contribution to ozone protection, if one considers that in many countries, particularly in low CFC-consuming countries, the by far larger amounts of CFC are used in the service sector and those will be saved. The usage of isobutane and/or blends as the refrigerant may by the way open a whole bundle of benefits in the service sector, e.g. due to the required care inhandling, for example using ready filled cartridges may in the end make not only servicing safer, but less costly. Dealing with the service sector will be part of the GTZ projects 1996/97, since in particular in the area of retrofitting substantial amounts of CFC could be phased out the quiet way.

Advantage 11

Technically simple to adopt

This Hydrocarbon Technology is relatively simple to adopt by comparison to "Chemicals". As already mentioned, e.g. same oils, same compressor type any factory is used to means less strain and stress on management and work floor This offers a whole range of tailormade adaptations of this technology into the real existing situation, which is different in each factory. So, generally spoken, here is a chance for each inhouse engineering department to come up with their "own" solution!

Advantage 12

No Patents,

No Licenses,

No Dependence

What was said about the independence this technology offers at the national level, applies, of course, to the company level as well. Here is the chance for any company taking the lead in setting up their own technical development, taking the lead in the market, taking the chance to set engineering consultancy for other countries as soon as have been through the process themselves. A good and convincing example is Haier Qingdao, after conversion of one of their factory lines now offers cooperation in the introduction of Hydrocarbon Technology to any Indian company In turn Indian industry may offer this to rest of the world in about one years time.

5

The Outlook:

The Hydrocarbon Domino is Running

It is the conviction of people working actively in hydrocarbon projects that this technology needs another good push - now. But soon market forces will keep it running! And that is the best that can be hoped for any ecologically-well-based technology. My plea to you is: Help to keep the hydrocarbon domino running in the right direction!

Thanks.

Energy–Saving Design of No–pollution Refrigerators

—— Application of CHs on the Refrigerators made by Haier Group Qingdao. China

Written by He Chuanqiao Wang Dongning Dong Changwei Lu Zhikun

A、Abstract

The following article introduces the work done by Haier Group on the CFC substitution, mainly exeperiences obtained from using CHs as foaming agent and refrigerant . It also describes changes of performances of refrigerators after being subjected to foaming agent of cyclopentane and refrigerant of isobutane , especially the realization of "zero pollution" to environment and super energy–saving. All these prove that CHs is a potential suitable CFCs substitute in the field of refrigeration.

B、Introduction

As an only enterprise of Chinese household electric products that has gained one of the Ten Famous Trade Marks, Haier Group is devoted to CFCs substitution and is the first Chinese manufacturer that has carried on the work of CFC–11, CFC–12 substitution, and has obtained many interim optimum achievements. There are more than 40 Chinese refrigerator / freezer manufacturers. Annually, about eight millions of refrigerators / freezers are made in China consuming large amount of ODS.

Methods of substitutions

CFCs	R12	R11
substitute	R22/R152a blend	50% CFC–11
	R134a	R141b
	R600a	cyclopentane

All these substitutes are in experimentation. In order to protect the environment of human being, Haier overcomed many difficulties such as large investments, devoting to this meaningful work. As a model factory of Chinese Government Environment Protection Bureau, China Light Industial Council, US Environment Protection Agency, GTZ and LIEBHERR Germany etc., cooperating to reduce ODS, Haier enforces the international technology cooperation, and takes Chinese special situations in account of carrying out a lot of researches about various substances for the foaming agent and refrigerant among these substitutions some oppointed by Montreal fund. All these substitutions have been realized the mass production in Haier.

In December 1994, one of its prodution line was altered to cyclopentane foaming, and its assembly line was changed to the production using R600a as refrigerant.and gained the safety Certification of TÜV. Its new model BCD-268 refrigerator realized zero pollution to the earth environment and its energy-saving reaches 50%, which exceeds the class A of "European energy consumption regulation". This is the first refrigerator that adopts CHs as the substitute in China and has obtained the optimum achievement in energy-saving. It also reduces the pollution caused by electricity generating. Following is a detailed description about the cyclopentane foaming and R600a being used as refrigerant:

C、cyclopentane as foaming agent

some production control parameters of cyclopentane foaming

1. purity of cyclopentane more than 70%.
2. Explosion-preventing safety system works.
3. Mould temperature should be controlled between 40-50℃
4. Ratio of foam agents: polyol: isocyanate = 445: 543
5. Density of foams range: 36-40kg / m^3

6. String time controlled between: 45−55S

7. Specialities of cyclopentane foamed cabinet as compared to normal 50% CFC foamed Cabinet. See the following table

foam system items	low freon	C−P system
average density kg/m^3	34.6	39.3
compressing strength Kpa	> 134	> 160
heat conductivity (mw/mk) 24°	18.4	20.4
stability of dimension (−30℃ × 168h)	< 0.5%	< 0.3%

From above, we can see that the cyclopentane foaming is feasible in factory, safety problems can be solved through altering of production line, but the defect of C−P foaming is causing the energy−consumption increases 5−8%. Therefore, refrigerators must be subjected to energy−saving design after CFC is substituted by C−P.

D、Refrigeration system adopting isobutane as refrigerant

1、comparison of properties of isobutane and that of R134a.

Properties of Flammable Liquid [ANSI/NFPA 325M, 1991]

	Ignition Temperature ° F (℃)	Normal Boiling Temperature ° F (℃)	Flammable Limits percent by Vol.in Air Lower/Upper	ODP/GWP *
Isobutane (HC600a)	860 (460)	11 (−12)	1.8/8.4	0/3
CFC−12	nonflammable	−21.6 (−29.8)	nonflammable	1.0/7100
HFC−134a	nonflammable	−15.1 (−26.2)	nonflammable	0/3200

* GWP compared to CO2; GWP−global warming potential;

ODP—ozone depletion potential [Greenpeace 1993]

2、Designing of refrigerator adopting isobutane as refrigerant

Climate class	N
Star Mark	* * * *
Volume (litter)	refrigerator 160L / freezer 108L
Thickness of foam (mm)	freezer 100mm、refrigerator 60mm
Foaming agent	cyclopentane
Compressor (Americold)	HC82、capacity 130W . COP1.4 (w / w)
Refrigerant	R600a : 65g
Control system	two way circulation by using solenoid valve, and temperature controlled sepereately
Dry filter	XH—5
Flow rate of capillary tube	adjust appropriately
Evaporator of refrigerator	hiden between inner liner and foam layer
Evaporator of freezer	plate—tube type , positioned as layers in the cabinet
Condensor	area 580mm × 1040mm
Model	BCD—268

you can see the refrigerant is R600a. It is well known that adopting R600a as refrigerant is more efficent than using R134a , became of compressor and other factors.

3、Results of performance test

Item	Test Dates	Test standard
Energy consumption	0.70kWh / 24h	ISO8187
Freezing capacity	20kg / 24h	
Temperature rise time	1800min (−18℃→ −9℃)	
Noise	39dB	
Storage temperature	N 32℃、16℃ qualified	

4、Analysis of results

Besides high freezing capacity and zero pollution to the environment, it also has a remarkable property : super energy-saving is very obvious, the European energy consumption potential: I= 45.31%, It has exceeded the class A of "European energy consumption regulation" (For class A, I<55%.)

E、Energy-saving Design

Energy-saving can attribute to the following factors.

* insulation layer thickening

The most direct method to save energy is to thicken the thermal insulation layer so as to reduce coldness leakage.

Energy-saving can reach 30% by this way.

* High-efficiency compressor

Adoption of high-efficiency compressor can save energy directly. The higher COP of compressor, the more effective of energy-saving. After using Americold HC82 compressor whose COP is 1.4, its energy-saving increases 15% in comparison to ordinary compressor.

* The optimum design of refrigeration system

1、Reasonable enlarge of condensing area

The condensing area of BCD-268 is enlarged 20% in comparison to ordinary one , Then it can both reduce the discharge pressure , and increase degree of overcold . Energy-saving can be reached also by this way.

2、suitable area of evaporators

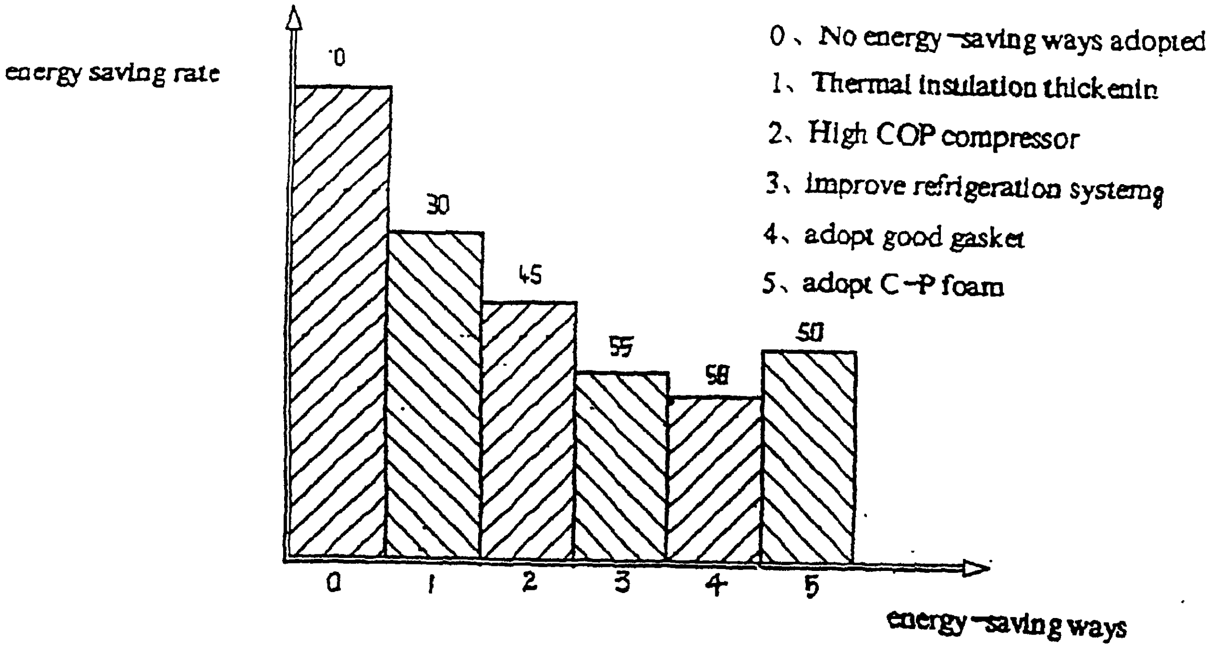
the area of the evaporator of refrigerator should be designed to meet the temperature of refrigerator 5℃ and that of freezer -18℃.Through reasonable monitoring of the area of refrigerator evaporator , energy-consumption can be reduced 5% -10%. Too small or too large of the refrigerator evaporator both can cause the increase of energy-consumption.

An reasonable on time rate of the compressor can be controlled by selecting suitable on /off temperature of the thermostat (on time rate= on time / on time +off time) If the compressor works short, the energy-consumption will be high because of the high start power; If the working time too long, the compressor will always work under low temperature of evaporation, in this case the compressor's COP is the lowest and energy-consumption will increases. Every system has a optimum range of working time, in which the refrigerators works most economically, Different types of refrigerators can reach the energy-saving 4-6% by adopting reasonable on-off time through experiment.

* Change the construction of door gasket

The design of door gasket should avoid cold air to contact the metal enclosure, and increase number of gas rooms, reduce the thickness of door gasket to reduce coldness distribution area.By reasonable desgin, it saves energy about 3%.

The proportion of energy saving of the methods mentioned above is indicated as below:



F、Conclusion

1、Good environment effects of CHs being used as foaming agent and refrigerant: ODP= 0, GWP= 0.

2、Refrigeration adopting CHs as foaming agent and refrigerant has good performance of refrigeration and super energy-saving.

3、Adopting safety measures in CHs production to avoid accidents.

4、Through various experiments of subsitution carried out by Haier, we can draw a conclusion:

CHs is an optimum substitute for environment protecting and energy-saving.

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THE PERFORMANCE OF HYDROCARBONS IN A HOUSEHOLD REFRIGERATOR /FREEZER

Evelyn Baskin and Richard B. Perry. EPA

ECO-REFRIGERATION: HIGHLIGHTS FROM INDIA

MR R S AGARWAL, IIT, DELHI
MR R S IYER, VOLTAS LTD., BOMBAY

ECOREFRIGERATION
CONFERENCE ON HYDROCARBON FLUIDS IN DOMESTIC AND COMMERCIAL REFRIGERATION APPLIANCES

ECO-REFRIGERATION : AN OVERVIEW OF HYDROCARBON TECHNOLOGY IN INDIA

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ABSTRACT

ECOFRIG project is an collaborative research project with the overall objective of the technology co-operation to assist Indian domestic and commercial refrigeration sub-sector in adaptive research, development and industrial application of ozone friendly energy efficient refrigeration technologies. The research Institutions such as Indian Institute of Technology, Delhi (IITD), National Chemical Laboratory, Pune (NCL) and Tata Energy Research Institute, Delhi (TERI) have been carrying out research and development on hydrocarbon technology for domestic and commercial refrigeration appliances in close co-operation with some of the domestic refrigerator manufacturers. This brief presentation highlights the studies carried out on the various aspects of hydrocarbon technology, such as design, development and evaluation of hydrocarbons as refrigerant, safety issues, standard & regulations during manufacture & use of hydrocarbon appliances and measurement of energy consumption in existing refrigerators under field & laboratory conditions.

ECOFRIG PROJECT

The ECOFRIG project was initiated with an exploratory visit by INFRAS/ DASAG Swiss Mission to India sponsored by Swiss Development Co-operation (SDC) in September 1992 while the concept of hydrocarbon refrigerator was at its infancy. The mission identified the scope for an Indo-Swiss joint project with some Indian refrigerator manufacturers (Godrej - GE Appliances Ltd, Kelvinator of India, Voltas Ltd.) and research institutions (Indian Institute of Technology, Delhi, National Chemical Laboratory, Pune). This was followed by an Indian delegation to Switzerland and Germany and later by a Swiss/German delegation to India in 1993. The Indian delegation was shown the manufacturing of refrigerators with propane-isobutane mixtures by FORON / dkk Scharfenstein in Niederschmiedeberg, Germany. This visit gave enough confidence to Indian delegation for further collaboration. A short term project was defined to carry out a Pre-feasibility study on suitability of hydrocarbon refrigerators under Indian conditions. This study was carried out by IIT Delhi [1] and NCL, Pune in close co-operation with some of the domestic refrigerator manufacturers. The results of this were encouraging and further study was undertaken.

A technical workshop was organised in March, 1994 at IIT Delhi in collaboration with FKW, Hannover where most of the Indian domestic refrigerator manufacturers participated. During the workshop IIT Delhi successfully converted and tested some Indian refrigerators with propane - isobutane mixture [2,5] . It was realised that there was a substantial scope of hydrocarbon technology in India.

Further collaborative research efforts continued at the research institutions and in the industry R&D laboratories. FORON and FKW were the collaborating partners from Germany. The German government also partially supported the joint project. Some Indian refrigerators were also tested with propane-isobutane mixture under retrofitting conditions with minor modifications both at FORON and by Indian Enterprises. The performance characteristics of these refrigerators with mixture were almost similar to those with CFC-12. Although use of this mixture also meant, no change in lubricating oil, no change in compressor except an increase in capillary length, but the leading German refrigerator manufactures introduced isobutane based refrigerators in Europe. The isobutane was preferred over mixtures of propane-isobutane due to a single component refrigerant, slightly better energy efficiency and low noise of the compressor.

In view of this development further research studies were undertaken by the research institutions to design, develop and performance evaluation of domestic refrigerators based on isobutane as well as isobutane-propane mixtures. The same have also been extended to commercial refrigeration appliances. The NCL, Pune have been studying the issues related to availability of hydrocarbons, lubricants and Indian & International standards for safety of such appliances. The present phase of the project is also aimed to study the various aspects including safety issues during servicing of hydrocarbon based domestic refrigerators and commercial refrigeration appliances.

Tata Energy Research Institute (TERI) in association with IIT Delhi carried out measurements of energy consumption in domestic refrigerators of different brands in the actual field conditions in the various parts of the country and for all the seasons. The test results were compared with that of laboratory tested.

Some of the domestic refrigerator manufacturers have considered Cyclopentane a foam flowing agent as an alternative to CFC-11. The cylopentane PUF technology will be demonstrated under ECOFRIG project at the two enterprises premises.

Recently a formal agreement between the governments of Switzerland, Germany and India and some of the industries have also been signed for the demonstration project for cyclopentane foam flowing.

STATUS OF HYDROCARBON TECHNOLOGY IN INDIA

Hydrocarbon technology both foam flowing and as refrigerant are being extensively under evaluation. Some of the domestic refrigerator manufacturers are actively considering cyclopentane and isobutane as potential alternatives to CFC-11 and CFC-12 respectively. The research institutions are closely associated in the process of evaluation along with some German research institutions and industries.

HYDROCARBON REFRIGERANTS

Hydrocarbon refrigerants have zero ODP and a negligible GWP [Table 1]. Their efficiency is slightly better than other leading alternative refrigerants and they are fully compatible with the lubricating oils conventionally used with CFC-12. The latent heat of vaporization of hydrocarbon refrigerants is very much higher in comparison to CFC-12 and its density is approximately one third that of CFC-12 making these refrigerants attractive because of its low charge requirements and circulation rates. However, hydrocarbons are flammable which requires a proper safe design of the appliance.

In Europe hydrocarbon refrigerants have successfully been introduced in domestic refrigerator-freezers. Almost all the major domestic refrigeration appliances manufacturers in Germany have converted the manufacturing facilities to isobutane as refrigerants and cyclopentane as foam flowing agents.

TABLE 1 Alternative Refrigerants to CFC-12 for Domestic and Commercial Refrigeration Appliances

Refrigerant	**CFC-12**	**HFC-134a**	**HC-290 / 600a**	**HC-600a Isobutane**
Formula	CF_2Cl_2	CH_2FCF_3	C_3H_8-C_4H_{10}	C_4H_{10}
Molecular Weight	120.93	102.03	51.12	58.13
Critical temperature	112.0	101.1	96.0	135.0
Boil point (100 kPa)	-29.8C	-26.16C	-30C	-11.73C
Density (kg/m3 ; -25°C) sat vapour sat liquid	7.57 1472.0	5.50 1371.0	3.14 584.4	1.66 608.3
Flammable limits (%in air), 20°C, 100 kPa	None	None	1.8-9.0	1.4-8.4
TLV/OEL	1000	1000	s.a.	1000
ODP	1.0	0	0	0
GWP	3.1	0.27	<0.01	<0.01

Table 2 presents the calculated relative performance parameters for mixture of Propane -Isobutane, pure Isobutane and HFC-134a as leading alternatives refrigerants to CFC-12 for a theoretical cycle having a -25°C evaporator and a +55°C condenser.

Table 2 **Comparative Performance Indices for the Leading Refrigerants for domestic Refrigerator**

Refrigerant	**CFC-12**	**HFC-134a**	**HC-290 / 600a**	**HC-600a Isobutane**
Formula	CF2 Cl2	CH2F CF3	C3H8-C4H10	C4H10
Volum.cap. (kJ/m^3), -25 C	1237	1185	1254	626
Press.ratio (-25/+55 C) subc. to 32 C	11.03	14.07	11.42	13.39
COP, theoret. (-25/+55 C) subc. to 32 C	equal HFC-134a	-	< to equal HFC-134a	>HFC-134a
Disch.temp. Theoretical (-25/+55 C) + suct.gas cooling (pract.)	120-125 170-175	115-120 150-155	105-110 140-145	100-105 135-140

Evaluation of Hydrocarbon Technology

Extensive performance evaluation of both mixture of propane - isobutane and isobutane have been carried out at IIT Delhi for domestic as well as for commercial refrigeration appliances. This section presents some of the results of these studies.

Propane-Isobutane Mixtures Based Appliances

The propane-isobutane mixture has the benefit of modulating capacity to permit their use with compressors designed for use with CFC-12. The binary mixture ratio can conceivably be designed using boiling point as a guideline such that the designed requirements of the freezer and the fresh food compartment in domestic refrigerators can be balanced. The normal boiling temperature for R-290/ R-600a mixture (each 50% by mass) ranges from -32°C to -24°C which is very close to normal boiling point of CFC-12, the current refrigerant. The mixture in comparison to CFC-12 possesses very high latent heat of vaporization and low value of density (1/3 of CFC-12) which makes the mixture attractive because of its low charge requirement and circulation rates. The charge levels are approximately 40% that of CFC-12. One of the important advantage of R-600a/ R-290 blends is that it is compatible with mineral oils and commonly used materials for manufacturing of refrigeration systems and requires minimal changes in the refrigerant system.

A number of Indian domestic refrigerators were modified by adjusting the capillary length desired for mixture of propane -isobutane. The performance of these refrigerators as per BIS 1476 was evaluated and compared with that of CFC-12 [6,8,9]. It has been observed that with a proper optimization of capillary length and amount of refrigerant charge, the performance is almost comparable with that of CFC-12. There is almost no energy penalty. The quantity of charge required is only 45 grams in comparison to 90 grams of CFC-12 [8] . This mixtures can be treated almost as drop in substitute. Some of the converted refrigerators to propane-isobutane mixture are in normal operation for the past about two years.

In the present phase of work a number of commercial refrigeration appliances, viz., visicoolers of various capacities and horizontal bottle coolers have also been converted to operate on propane-isobutane mixture. The performance of these appliances is also almost similar to CFC-12 if length of capillary and amount of charge is optimised. These appliances are also in operations for the past 6 months.

Isobutane Based Appliances

Isobutane is a single component hydrocarbon refrigerant with a normal boiling point of -11.85°C. This refrigerant inspite of having sub-atmospheric pressure at suction has been widely considered as one of the practical solution for small capacity refrigeration appliances such as domestic refrigerator-freezers, visicoolers, deep freezers, chest freezers and water coolers etc. Here at IIT Delhi a long term program has been taken up to asses the potential of isobutane as an alternative refrigerant under Indian conditions.

In the first phase of the study an isobutane compressor was designed and developed using the existing Indian compressors suited to 165 litre domestic refrigerators. Subsequently one of the Indian 165 litre refrigerator was modified to operate with isobutane refrigerant in April, 1995. Further optimization of capillary length and the amount of refrigerant charge was carried out to achieve energy efficiency. The performance of modified refrigerators is almost the same as that of CFC-12 [8]. Some of the domestic refrigerator industry also developed such compressors and performance evaluation tests have been carried out. The study demonstrated that isobutane technology does not require and any change in process of manufacturing except due safety precautions. The similar approach has been also adopted for commercial refrigeration appliances.

SERVICING OF HYDROCARBON APPLIANCES

Hydrocarbon refrigerants are free from halogen elements, compatible with mineral oils and do not have chemical reaction with the commonly used materials in manufacturing and servicing of refrigeration appliances. Thus the practices of servicing of hydrocarbon appliances would not require any substantial change. The isobutane are mixture of propane-isobutane compressors can also be serviced including the servicing of valve plates, motor winding etc., as per the prevalent practices used for CFC-12 compressors in India. Only due care is to be observed during charging of refrigerant i.e., avoidance of ignition source.

COMPARATIVE STUDY OF ISOBUTANE AND HFC-134A TECHNOLOGIES

Table - 3 presents a comparative study of HFC-134a and isobutane / propane-isobutane mixture technologies from the point of view of manufacturing and servicing.

Table 3 Comparison of HFC-134a and Hydrocarbon Technologies

HFC-134a	HYDROCARBON TECHNOLOGY
Lower system Efficiency	Higher system efficiency
Deep change in compressor manufacturing processes	No change in compressor manufacturing processes
Highly sensitive to moisture content	Negligible sensitivity in moisture content
High degree of cleanliness for the whole refrigeration system	Prevalent order of cleanliness is Acceptable
Higher potential of system malfunction due to accidental pollution	Negligible effect
relatively higher noise level	Low noise level with isobutane as refrigerant
Non-flammable	Flammable
Higher cost of refrigerant and lubricant	Low cost
Essential to upgrade servicing practice	Existing service practice may be followed with safety precautions
No safety measures are required	Safety measures are required

SAFETY STANDARDS AND REGULATIONS FOR THE MANUFACTURERS OF HYDROCARBON APPLIANCES IN INDIA

A detailed study was under taken by National Chemical laboratory, Pune to look into the various aspects of safety issues to be addressed in adopting hydrocarbon technology in India. The study outlined the measures to be considered in various stages such as storage, manufacturing, use of hydrocarbon appliance and servicing [7]. It has also been suggested that there are safety guidelines available in some of the other countries like Germany which can be easily be adopted in our country.

ENERGY CONSUMPTION OF INDIAN DOMESTIC REFRIGERATORS UNDER FIELD AND LABORATORY CONDITIONS.

Tata Energy Research Institute in collaboration with IIT Delhi conducted an exhaustive study under ECOFRIG project the measurement of energy consumption in the field and laboratory conditions [11]. During this study average energy consumption of Indian refrigerators was measured under field and laboratory conditions (as per Indian Standards 1476) in four climatic zones covering different regions of India. A total 155 house hold were surveyed for three brands of 165 litre refrigerators very interesting. The main objective the study was to establish a base line of energy consumption level in such appliances under field conditions. The results have been

CONCLUSIONS

Based on the studies carried out and experienced gained by the research institutions an the collaborating Indian domestic refrigerator manufacturers by way of interaction and visits to the manufacturing facilities of hydrocarbon based appliances in developed countries following conclusions may be drawn :

1. Hydrocarbon technology is a promising and proven technology for domestic and commercial refrigeration appliances.
2. This technologies does not require any change in the process of manufacturing of compressor, appliances and other components used in these appliances
3. The safety issues arising due to flammable nature of refrigerant needs due considerations. The amount of charge is so small that safety issues can be taken care of with the present level of technical know how.
4. The existing service practices especially the repairing of hermetically sealed compressors would not require any major change except training of technicians for handling of flammable refrigerants.

ACKNOWLEDGEMENTS

Support to the research institutions by Swiss Development Co-operation, Switzerland, GTZ Germany, INFRAS Switzerland and Indian Domestic Refrigeration Manufacturers is gratefully acknowledged.

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ECO-REFRIGERATION

Cooperation - Experience & Background Highlights from India

Mr R S Iyer, Voltas Ltd., Bombay

Introduction

This co-operative Project between Swiss Development Cooperation (SDC) and the Indian Industries had its origins in September 1992 when Dr. Othmar Schwank of Infras AG (a Swiss Environment Consultancy) along with Dr. Hari Sharan of Dasag Ltd. (A Swiss Energy Engg. Consultancy) called a meeting (on behalf of the SDC) in Bombay to know about the interest that the Indian Industry may have to use Hydrocarbons fluids in Domestic Refrigeration. Although the Indian industry had hardly ever known of Hydrocarbons being used as Refrigerants or as Insulation Foam Blowing Agents, two Indian Companies (Refrigerator Manufacturers) and two national R&D Institutions agreed to participate in the Project purely from an 'R&D' perspective.

From Scepticism to Belief

The SDC, through Infras, arranged for two visits of Indian Industry to Europe - one in 1993 and the other in 1994. These visits removed much of the initial scepticism that the Industry had on the use of Hydrocarbons on a large scale. The 1993 Europe visit enabled the Indian Companies to see the transformation that had just begun in Germany in the use of Hydrocarbons as Refrigerants and as Foam Blowing Agents. Foron GmbH, an East German Company, had spearheaded the change, using Hydrocarbon Mixtures as Refrigerants.

Workshops were conducted at IIT-Delhi in February 94 with faculty from FKW (Institution of Refrigeration), Hannover, where R&D Institutions and four Indian Refrigerator Manufacturers participated.

The Project inter alia included 'Refrigerator Testing' and three Indian Companies sent their Refrigerators to Foron; for testing with Hydrocarbon mixtures as 'Refrigerants'. In addition, the Indian Partners were also provided with samples of Hydrocarbon Mixtures to carry out their own trials in their Laboratories.

Transformation in Germany - The Hydrocarbon Reality

The 1994 Europe visit (of three Indian Refrigerator Manufacturers) included visits to German Refrigerator manufacturers - Liebherr, AEG and Foron and attending the Hannover International Conference on 'Natural Fluids and Hydrocarbons'. This visit confirmed the reality of the use of Hydrocarbons as a Refrigerant and also as a Foam Blowing Agents. German manufacturers, who had first used Synthetic fluids like HFC 134a as Refrigerant and Halogen-based Foam Blowing Agents, had switched over to Iso Butane as a Refrigerant and Cyclopentane as Blowing Agent. A visit to the independent German Safety Agency - TUV Energie und Umwelt GmbH, ULM gave an insight of the stringent safety measures insisted on by TUV whilst certifying the installations using Hydrocarbons. The results of the tests conducted on the Indian Refrigerators at Foron were discussed and analysed.

The most important outcome of this visit was the 'cooperative understanding' entered into between two Indian Refrigerator Manufacturers and the SDC for the setting up of a 'Pilot Cyclopentane Foam Blowing Plant' at their factories on an equal cost sharing basis. To a great extent, this was facilitated by the presence of two senior Govt. of India officials who were present at this meeting in Germany when this decision was taken. This exercise would enable the Indian participating Companies to gain a first hand experience in the handling of Cyclopentane and in carrying out adaptive research and application engineering , leading to pilot production. The understanding also included plans for studying the possible use of Hydrocarbons as Refrigerants in India.

Action Phase (1995)

The understanding arrived at was then formalised through the Indo-Swiss Government to Government agreement and the MoU signed between the Industry Partners, Infras (on behalf of SDC) and the MoEF (Ministry of Environment and Forests, Government of India).

Agreement were also entered into between :

[a] Industry Partners, Infras AG, FKW (Germany) for carrying out life testing of Indian Compressors using CFC-12, Hydrocarbon Mixtures and Isobutane.

[b] Industry Partners Infras and DKK (Germany) for carrying out Calorimetric testing of Indian prototype of Compressors, using Isobutane.

[c] Afros SpA (Cannon) Italy and Plasttechnik Greiz (Germany) Consortium, Industry Partners, Infras for the supply of Foaming Machine with one set of fixtures for Cabinet and Door for the use of Cyclopentane as a Blowing Agent.

[d] Infras, Liebherr (Germany) and Industry Partners for studying the changes needed in Direct-Cooled and Frost-Free Indian Refrigerators for using Isobutane as a Refrigerant.

While the Calorimetric Tests have been completed, the Life Testing is almost coming to a close. The consignment of Foaming Plant and equipment is scheduled for despatch from Europe by the end of January/early February.

The Results -

The objective of this cooperative Project was to introduce and familiarise Indian Industry with the use and advantages of Hydrocarbons in lieu of Synthetic Chemical fluids. The flammability and safety precautions needed whilst handling Hydrocarbons have also received special attention and care. With commissioning of the Pilot Foaming Plant, the Indian manufacturers will get first hand experience on the use of Hydrocarbons at the Plant level and in the safety measures that are needed for h andling of Cyclopentane. This should give Industry the necessary confidence in the care and precautions to be taken whilst handling flammable and explosive fluids. Cyclopentane, as a Blowing Agent, ranks high as a first choice for the Indian Industry Partners.

Regarding Hydrocarbons, as Refrigerants, the pros and cons of their use are being seriously studied, weighed and debated and the results of the Sub-Project at [d] above should go a long way in shaping the decision.

A Unique Project -

The Project has been a unique cooperation exercise. It has brought together Industry Competitors, National Research Institutions, three Governments (Swiss, German and Indian) and German and Italian Industry all working harmoniously and cooperatively. A special mention has to be made on the role of Infras (acting on behalf of the SDC) who have acted as live wire project cordinators and Implementors and who have brought these Projects to such an advanced stage.

Acknowledgement

The Indian Partners wish to acknowledge and thank the following Organisations for their unstinted help and co-operation :

- ✡ SDC AND INFRAS
- ✡ GTZ AND GERMAN INDUSTRIES (FORON, LIEBHERR AND FKW)
- ✡ CANNON, ITALY
- ✡ PTG , GERMANY
- ✡ TUV GERMANY
- ✡ MINISTRY OF ENV. & FORESTS GOVT OF INDIA
- ✡ INDIAN R&D INSTITUTIONS (IIT DELHI, NCL PUNE & TERI)

HC600a, HC BLENDS AND HFC134a: PERFORMANCE, MANUFACTURING, COSTS FROM THE COMPRESSOR POINT OF VIEW

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HYDROCARBON CONFERENCE

SESSION II :HYDROCARBON REFRIGERANTS IN DOMESTIC AND COMMERCIAL REFRIGERATION

CFC REPLACEMENTS: R 600A R 134A
PERFORMANCE , MANUFACTURING , COSTS
FROM THE COMPRESSOR POINT OF VIEW

NECCHI COMPRESSORI
PAVIA, ITALY

DELHI, FEBRUARY 13 / 14 1996

CFC REPLACEMENTS: R 600A R 134A PERFORMANCE , MANUFACTURING , COSTS FROM THE COMPRESSOR POINT OF VIEW

DELHI FEBRUARY 13 / 14 1996

NECCHI COMPRESSORI - ITALY

ABSTRACT

Although the CFC phase out has already been decided and since some years all over the world many manufacturers have been working on this, the final solution accepted globally has not been identified yet

Furthermore, many countries who have not yet operatively implemented any non-CFC solution are evaluating some alternatives

In this presentation, starting from the physical data related to the different solutions, some considerations will be done taking into consideration design, manufacturing consequences and possible related costs
The point of view will be the compressor manufacturing

Also some considerations will be done on retrofitting the existing CFC refrigerators when this gas will be no more available

1. THEORETICAL PERFORMANCE

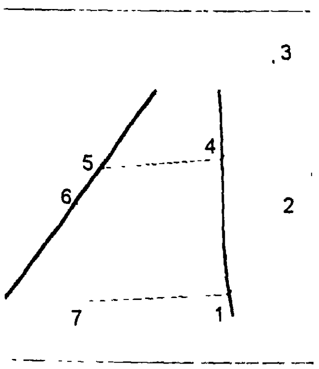


Fig 1 - Ideal reference cycle for the performance calculations

The theoretical comparison of the performance of different refrigerants, including blends also, requires the definition of a test method which, in the case of non azeotropic blends, is not perfectly identified the different characteristics of the blend components can give non fully isothermal state transition paths and this temperature glide can originate some indeterminations in the test conditions

The theoretical cycles taken into consideration have the vapour over heating and liquid subcooling temperature coincident and set at 32°C

The condensing temperature is +55 °C and the main comparisons are at -23 3 and -30 °C

In fig 2, 3, 4 the calculated performance are reported in comparison between R12 and an hydrocarbon blend in which the X axis is the R290 percentage.

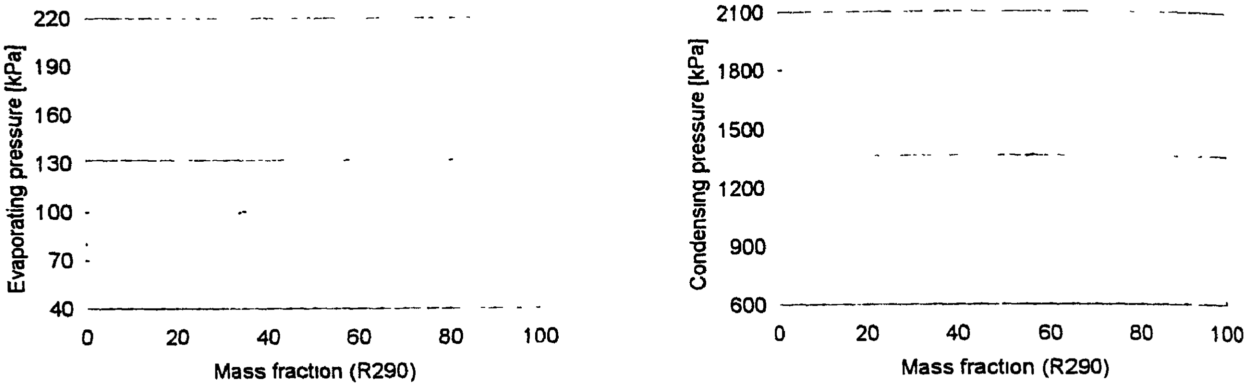


Fig 2 - Evaporating and Condensing pressure of R290 600a blend in ideal cycles with 55 °C condensing temperature and -23 3 °C (———) and -30 °C (- - - - -) evaporating temperature The straight line is related to R12

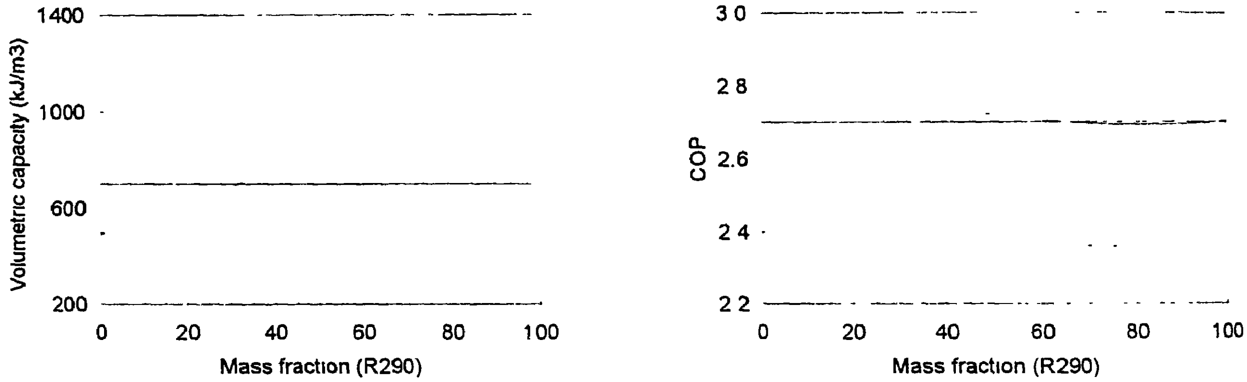


Fig 3 - Cooling capacity and efficiency (C O P)

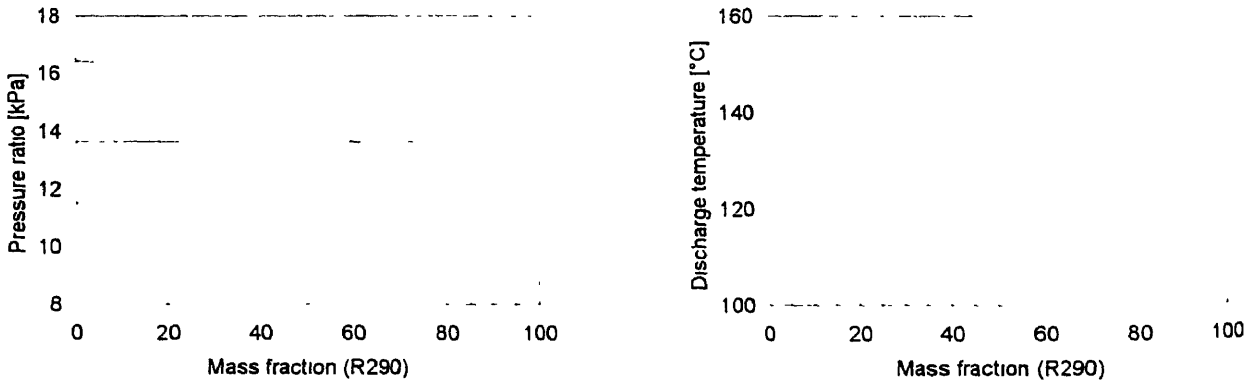


Fig 4 - Compressor discharge pressures ratio in comparison with R12

In the following chart 1 the main characteristics are reported numerically to allow some considerations

Chart 1 - Theoretical performance of some R12 replacements

				R12	R134a	R600a	R290/600a (50/50)
55 °C	discharge pressure	p_5	(kPa)	1364	1495	772 2	1296 7
	liquid enthalpy	h_6	(kJ/kg)	230 7	244 0	275 0	279 0
	Δt condenser	t_4-t_5	(°C)	0	0	0	6 43
-30 °C	suction pressure	p_2	(kPa)	100 1	84 28	46 95	91 3
	compression ratio	ρ	(-)	13 63	17 74	16 45	14 20
	suction density	d_2	(kg/m$^{3)}$	4 861	3 440	1 089	1 837
	Δt evaporator	t_1-t_7	(°C)	0	0	0	5 78^{-}
	refrigerating capacity	h_2-h_7	(kJ/kg)	144 1	187 7	334 6	346 0
	volumetric capacity	d_2*(h_2-h_7)	(kJ/m$^{3)}$	700 5	645 7	364 4	635 6
	compr discharge temp	t_3	(°C)	139 06	129 55	111 19	120 72
	theoretical COP	COP	(-)	2 36	2 39	2 53	2 39
-23 3 °C	suction pressure	p_2	(kPa)	132 0	114 6	63.2	121.2
	compression ratio	ρ	(-)	10 33	13 05	12 22	10 70
	suction density	d_2	(kg/m$^{3)}$	6 45	4 703	1 471	2 454
	Δt evaporator	t_1-t_7	(°C)	0	0	0	5 58
	refrigerating capacity	h_2-h_7	(kJ/kg)	143 7	187 3	334 0	345 0
	volumetric capacity	d_2*(h_2-h_7)	(kJ/m$^{3)}$	926 9	880 9	491 3	846 6
	compr discharge temp	t_3	(°C)	128 25	120 09	103 47	112 33
	theoretical COP	COP	(-)	2 70	2 73	2 79	2 73

1.1 SOME CONSIDERATIONS

1 1 1 Suction pressure almost equivalent for R12, R134a and R600A/290 blend, much below the atmospheric pressure for R600A particularly for low evaporating pressures

This fact makes more critical the gas leakage on the suction side of the circuit as air ingress is possible and system pollution is a consequence

1 1 2 Discharge pressure also similar for the three mentioned refrigerants but approximately ½ for R600A, this will produce less stress and pulsations of the gas in the discharge side with potentially lower noise

Note on noise the common sense would make one think that noise reduction can come as a direct consequence of the lower discharge pressure but this is not always true, the acoustical impedance of a gas is directly proportional to the density and the density of the R600A is much lower than the other refrigerants at any operating conditions

For this reason the noise reduction can become actual but after a fine tuning of all the internal components of the compressor affecting the acoustical radiation, particularly on the suction side where the gas pulsations are involving a wide surface and therefore a high sound power

1 1 3 Specific volumetric capacity this is the most important factor of the R600A conversion as it is approximately ½ than the other alternatives, as a consequence, keeping constant the cooling power of the system, the displacement of the compressor must be increased.

The biggest effort made by compressor manufacturers has been concentrated in using all the design techniques to reduce as much as possible this displacement increase improvement of the volumetric efficiency, reduction of the gas temperature to increase its density at the suction etc have been applied and in general, the displacement increase has been limited to 70 - 80 %.

1 1 4 Theoretical efficiency the R600A one is higher than the others and the related impact on the GWP (Global Warming Potential) is smaller Of course the actual efficiency on refrigerators must be checked because it is known that the normal life cycle of a refrigerator is made by a continuous alternance of non-steady state situations and that is significantly different than the theory

1 1 5 The last thing to observe is related to the working parameters of the R290/600A 50-50 blend they are significantly similar to the R12 or R134a ones (an optimal condition would be at 60 40 ratio which optimises the efficiency)

This should be taken into account for the considerations about retrofit that will be done at the end of this presentation

2. APPLICATION

This comparison is made at different levels

First of all at the level of the compressor tested on the calorimeter this will allow some considerations coming from the actual behaviour of the compressors not only as far as the thermodynamic characteristics are concerned but also for the indirect consequences of other parts affecting the energetic behaviour of the compressor itself
This will involve the acoustic radiation also

The second level is on the application giving the idea of the changes required for the tuning of the ecological compressors on the appliance

2.1 COMPRESSOR TESTS

The first comparison, at compressor level, is reported in the enclosure n 1 which includes the cooling capacity and the C O P evaluations on a typical compressor produced at large volumes (5,5 cc tested with the different refrigerants and, in the case of the High Efficiency version, with the run capacitor)

2 1 1 COOLING CAPACITY

It is evident the confirmation of the theoretical data the R134a application is producing slightly lower capacity than R12 and R600A is at about 50 % in all the evaporating temperatures range and this is confirming the need to increase the displacement of the compressor to get the same performance on an appliance
To be pointed out also the R290/600A blend as having similar capacity as the R12

2 1 2 C O P

The improvement obtained with the blend using the run capacitor is significantly higher than the expected The run capacitor is usually giving approximately 8 - 10% of efficiency increase,

The high value measured has been interpreted as coming by a positive "side-effect" of the general temperature decrease inside the compressor this seem to give higher benefit with HC than with the other refrigerants
Anyway this statement has not been investigated further
As to the R600A, this is showing better values than R134a and this is also consistent with the theoretical calculations

2 1 3 GLOBAL PERFORMANCE COMPARISON

R 600 A

Model	Displac c c	Cool Cap Kcal/h	E E R w/w(*)
HGTR4 5	4 7	60	0 99/1 1
HGTR5 5	5 5	74	1 05/1 16
HGTR6 5	6 5	86	1 1/1 17
HGTR8	8 2	109	1 12/1 21
HGSR9	9 1	122	1 23/1 34
HGSR11	10 6	140	1 28/1 39
HGSR13	12 5	160	1 30/1 41
HGSR15	15 1	203	1 29/1 40

R 134 A

E E R w/w	Cool Cap Kcal/h	Displac cc	Model
0 93	65	3 5	ETR3 5
0 98	75	4 1	ETR4
1 07	101	5 12	ETR5
1 10	112	5 55	ETR5 5
1 16	127	7 0	ESR7
1 15	148	7 75	ESR8
1 17	160	8 2	ESR8 5
1 15	212	10 6	ESR11

(*) Before and after the "/" are reported the values without and with the run capacitor

The compressors of the two series, horizontally compared, are exactly of the same overall dimensions

2.2 FRIDGE / FREEZERS TESTS

In the attached chart is reported the synthesis of some tests carried out on refrigerators of various kinds with the main objectives to

- Identify the behaviour of refrigerators with only the gas charge and the compressor change
  In none of the tests the heat exchanger have been modified
- Check some of the applications from the retrofit point of view

2.2.1 CONSIDERATIONS ON THE REFRIGERATORS BEHAVIOUR

2 2 1 1 The use of R600A confirmed the need of compressors with a significant increase in displacement but the rate of increase is smaller than expected looking at the theoretical data
The reasons of this aspect come from two origins

The actual compressors temperature along the thermostat cycles with R600A (and HC blend also) are lower than the ones put into the theoretical calculations therefore the gas density and the consequent volumetric efficiency of the compressors was better, this aspect is amplified with the use of the run capacitor

The reference performance were measured on refrigerators taken directly from the production lines and, particularly the R12 ones , had systems not optimised on the energetic point of view.

2 2 1 2 The results in energetic consumption showed themselves very sensitive to the refrigerant charge. if R12 or R134A systems could tolerate variations in the gas quantity of some 10 - 20 g, the HC ones changed their behaviour in a perceptible way with ± 5 g only

The consequence of this is the choice of the process filling machinery which must be more accurate than in the past.

2.2.1.3 Always the results have been positive to the R600A use , the fact that the gas density it has shown itself very positively affecting the global efficiency of the compressor has supported the decision to generally provide compressors for R600A with run capacitor whose effect in the efficiency improvement is significant.

2 2.1.4 The HC blend R290/600A (50-50) can be considered a drop-in refrigerant for R12 as far as performance are concerned, of course the use of it as retrofit must be carefully analysed because of the flammability and safety issues· the refrigerators to be eventually retrofitted were not originally designed to work with flammable refrigerant

2.2.2 NOISE

All the noise evaluations have been originally carried out in the convincion that the lower the discharge pressure, the lower the noise radiation and this is partly true but in some experiences this was not demonstrated

In general the application of R600A on refrigerators produced an average reduction of 2 dB(A) vs. the corresponding R12 and even 3-4 dB(A) vs. the R134a applications but on some refrigerators we assisted at a slight increase and this was not understood at the origin.

A further investigation, carried out while making some design improvements on a compressor family expressly designed to be suitable for R134A and R600A, showed us that much care must be put on the gas pulsation on both, the suction and the discharge side of the system
As a matter of fact, if for some reasons the peak factor of the gas pulsation were high, the noise reduction effect using R600A was zero and this can be only explained with the physical characteristics of the R600A

The acoustical impedance $Z=\frac{p}{v}=\frac{p}{\sqrt{\rho rT}}$ where p=sound pressure, ρ=gas density

of the gas is lower with R600A and in general with HC than with R12 and R134A

GAS TYPE	SOUND SPEED Co[M/S]	IMPEDANCE Zo [Pa*s/m]
R12	165	913.5
R134A	180	700.2
R600A	238	279.6
AIR	381	372.1

These data are calculated with gas temperature of 90°C and pressure corresponding to the evaporating temperature of -23°C for each refrigerant (1 35 bar for air)
The big difference in the acoustical impedance and in the sound speed, can explain, for instance, that the first natural pulsation modes are located at higher frequency levels for R600A
They are more likely to be nearer the high ear sensitivity field, furthermore they are transporting the higher acoustical energy content, for this reason much care must be put to the gas pulsation to get the best advantages by the lower working pressures

FRIDGE FREEZERS TESTS

SINGLE DOOR REFRIGERATOR

Nominal Volume [l]	1 40		1 70		190			140		
Refrigerant	R12	R600A	R12	R600A	R12	R134A	R600A	R12	R134A	R290/ 600A
Charge (g)	110	40	120	58	75	73	27	80	87	25
Compress Type	4 cc	6 5 cc	4 cc	6 cc	3 cc	3 cc	4 5 cc	4 cc	4 cc	4 cc
Fridge T °C	5	5	5	5	5	5	5	5	5	5
Frz Temp	-18	-17 5	-9 4	-8 7	-	-	-	-8 3	-9 1	-8 5
Energy Co [Kwh/24h]	1 12	1 07	1 16	1 06	1 09	0 93	0 87	1 14	1 13	1 08
Running %	47	51	43	42	52	47	48	37	40	43

DOUBLE DOOR FRIDGE-FREEZER

Nominal Volume [l]	180 + 60		260 +7 0	
Refrigerant	R12	R290/600A	R12	R290/600A
Charge (g)	110	50		
Compress Type	5 cc	5 cc	8 5 cc	8 5 cc
Fridge T °C	5	5	5	5
Frz Temp	-20 5	-19 5	-13	-16 4
Energy Cons [Kwh/24h]	1 65	1 52	2 47	2 32
Running %	66	58	69	63

VERTICAL FREEZER

Nominal Volume [l]	120		290		250		140		
Refrigerant	R12	R290/ 600A	R600A	R290/ 600A	R12	R600A	R12	R134A	R600A
Charge (g)	95	56	54	50	160	65	110	100	37
Compress. Type	5.5cc	5 5 cc	13 cc	8.5 cc	7 cc	11 cc	4 cc	5 cc	8 cc
Fridge T °C									
Frz Temp	-18	-18	-18	-18	-18	-18	-18	-18	-18
Energy Co [Kwh/24h]	1 43	1 50	1.41	1 48	1 86	1 62	1 25	1 37	1 24
Running %	40	49	35	40	55	62	56	55	51

3. TECHNOLOGICAL CHANGES ON THE COMPRESSOR SIDE

All the changes in the compressor technology are concentrated in two main branches

3.1 Displacement increase

The ideal goal of a good compressor manufacturer would be to replace the compressor for R134A or R12 with a R600A one having the same overall dimensions and the same cooling capacity

But this is not always possible as, for example, 160 Kcal/h can be obtained with a 8cc with R134A or with a 13 cc with R600A and not all the compressor design allow such an increase, therefore in some cases the step up in the compressor family is required

In the experience carried out by Necchi there has been the full success in the replacement but the design effort has been big and with some surprises to be faced

3 2 Lubricant

It is well known that with R134A the use of Poliol Ester lubricant is necessary

As a consequence of this the compressor and refrigerator manufacturers had to face some undesired "side-effects" like

Hygroscopicity Higher with POE oil than with mineral lubricant
Thermal stability critical point particularly with additives (antiwear etc)
Solubility of refrigerant not all POE lubricants get it at all temperatures
Material compatibility to be inspected with all the traditional materials used in refrigerating systems, Chlorine is an example

All these aspects are potentially producing the formation of sludge inside the capillary tube of the refrigerating systems and then the progressive performance deterioration

Some notes on the mechanisms of formation of the mentioned sludge can be useful

3 2 1 Excessive moisture content
Through the hydrolysis of the oil, an acid appears which, as final compound, generates carbossilates (metallic salts)
To prevent this a good compressor and system dehydration must take place, the proper molecular sieve must be used and avoided as much as possible any additivation which could act as catalyst for the chemical reaction

3 2 2 Excessive oxidation of the oil the final compounds can also be metallic salts coming from the combination of ester decomposition and metallic ion
A high level of vacuum can avoid this

3 2 3 Chlorine combined with heat can produce the ester decomposition giving the same consequence as before
Chlorine must be avoided weather it is coming by polluted systems or if it is coming by chlorinated cleaning agents

3 2 4 Temperature can give the deterioration of the ester oil eventually promoted by impurities coming from system pollution (process mineral lubricant, oligomers extracted by plastics inside the systems are examples of potential catalyzers)

It can be well understood that the cleanliness of the refrigerating systems is vital for its good long term behaviour

Instead, in the case of R600A and HC blends, the lubricant can also be of mineral origin and no problem is coming from the abovementioned things
Nevertheless the very good solubility of the HC refrigerant with mineral oil must be "managed" as some other problems can take place

If the amount of refrigerant is high)but this is only the case in big refrigerators or commercial applications, the lubricant viscosity can be heavily affected by the dilution
The traditional naphtenic lubricants have the attitude to generate foam in the transitory of initial extraction on the refrigerant in liquid solution, therefore, much attention must be paid to the lubricant choice
If the foaming takes place at microscopic level between the friction surface, the lubricant film can be broken with negative effects on the long term wear

4 FLAMMABILITY

The flammability, as a matter of fact, becomes a very weak point considering the very small amount of refrigerant present in any domestic system
Nevertheless some simple features can prevent any risk the use of a flame quenching overload protector with a PTC starting device eliminates any ignition point near the compressor
Similarly other changes, applied in the food storage compartments can eliminate any risk

5 COSTS

As a consequence of the above said elements, it can be well understood that the cost of a R600A compressor is equal or lower than the R134A one of the main reasons of this is the much lower cost of the mineral oil vs the ester one.

Anyway this is valid for the compressor displacement ranges in which it has not been necessary to change too many things to obtain the displacement increase in the same overall dimensions

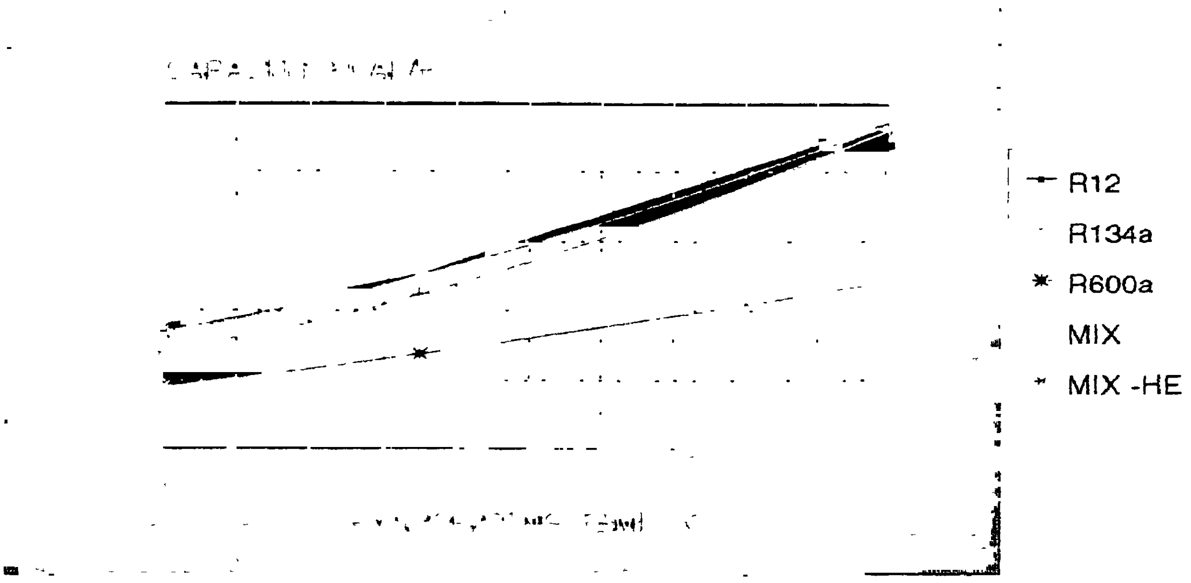
Any other consideration on the refrigerant and other system components costs must be done on the refrigerator Manufacturer side

CONCLUSIONS

The experience demonstrated that R600A can be a good refrigerant for domestic application which, in this case, become fully ecological and with high efficiency
The global costs of such a refrigerating system is not higher than a R134A also considering the changes needed to prevent any risk coming from the flammability of the gas
The global efficiency of compressors designed for this application show this refrigerant a good efficiency one
To be outlined the specific performance of R290/600A (50 - 50 or 60 - 40) which are so similar to the R12 ones to identify these blends like thermodynamically drop in solution

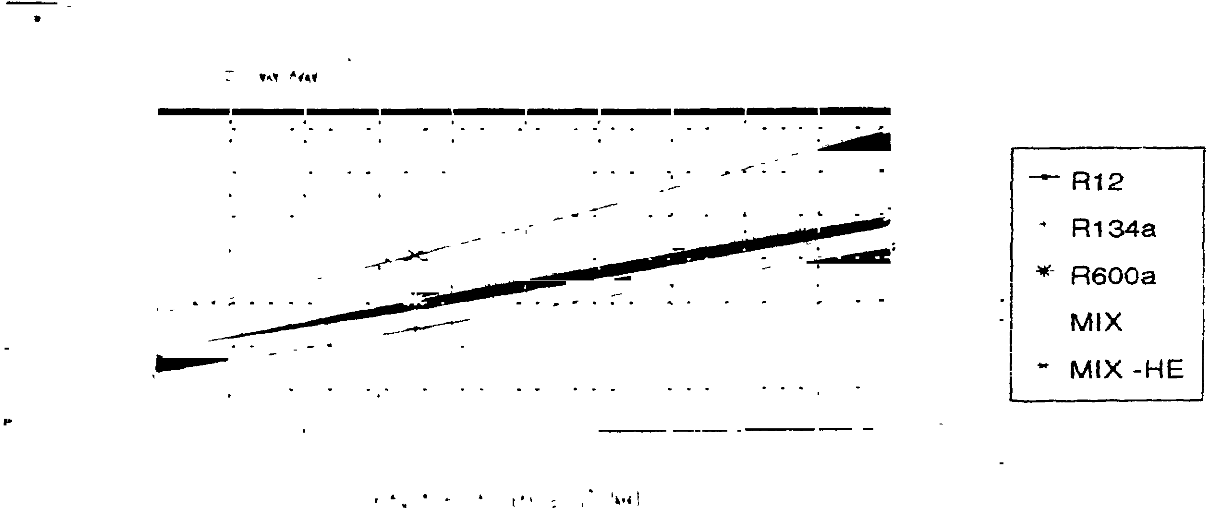
MEASURED CAPACITY

TYPICAL COMPRESSOR . 5.5 CC



MEASURED EFFICIENCY

TYPICAL COMPRESSOR 5 5 CC



HFC134a AND HYDROCARBON APPLIANCES IN DOMESTIC REFRIGERATION: MARKET TRENDS, CONVERSION

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ECOFRIG
Hydrocarbon Conference
Delhi 13.-14.02.1996

HFC134a and Hydrocarbon Appliances in Domestic Refrigeration: Market Trends, Conversion

The Change to Hydrocarbon Refrigerators and Freezers

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THE CHANGE TO HYDROCARBON REFRIGERATORS AND FREEZERS

INTRODUCTION

Thank you very much for giving us the opportunity to introduce the LIEBHERR contribution to environment protection with CFC's / HFC's phase-out technology.

Details about the development of alternative refrigerants and foam blowing agents and the practical use of Hydrocarbon (HC) in foaming and final assembly as well as after sales service will be given by other experts of this workshop.

The set up deadlines for the phase-out of CFC's are in general according to the Montreal protocol. For Europe it had been set up as per 1996 and for Germany, Austria, Switzerland and Sweden already in 1995. The deadline for HCFC's is set for the year 2030, whereas for Europe 2015 and even Denmark committed to phase-out in 2002.

I would like to give you now some more information about worldwide phase-out of CFC's and specially the development of LIEBHERR in this specific sector and our qualification to share our experience in HC technology with co-operation partners all over the world.

As a member of the strongly diversified LIEBHERR GROUP acting worldwide with activities in the production of construction machinery (cranes, earthmoving equipment, machine tools, material flow technology and aircraft technology) we have an experience of more than 40 years in refrigerator and freezer production, which we share since more than 17 years with technical partners worldwide.

In production facilities of more than 100'000 m² we manufacture 1,5 million refrigerators and freezers (household and commercial) per year in Germany and Austria.

FOAM CONVERSION

Being a market leader in Germany and a major producer in Europe requires innovations in new developments, especially in CFC and HFC-free conversion and energy-saving as the main targets in our days.

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THE CHANGE TO HYDROCARBON REFRIGERATORS AND FREEZERS

As most manufacturers, LIEBHERR started years ago to study and check all possible alternatives to replace the 50% reduced R11 foam by a clean solution. This was also done in the framework of the German electrical industry association (ZVEI), where all important European manufacturers participate. PAFT programmes were involved too.

LIEBHERR was looking for a final, not an intermediate solution, in order to change production equipment only once. The aim was:

ODP = O
GWP ~ O

and a very short atmospheric life span (Hydrocarbons 2-3 days; R134a ~ 16 years; R11 ~ 100 years). Through former experience and a patent on Pentane, LIEBHERR started to work on this project in 1992. It took more than one year to come to the production level.

Within this time, patent rights had to be cleared, developments of new appropriate foam components had to be initiated and material specifications as well as recipe formulas to be worked out. At that time this was rather new, whereas nowadays you will get all these things ready made from specialised manufacturers.

For the processing of Cyclopentane no existing example for this particular production was existing.

Through critical risk diminution new safety systems were laid out together with the German TÜV (German technical association for inspection/acceptance) and had to be tested and accepted. Even the discontinuous procedure (single short shots of foam injection) had to be solved.

C-Pentane has been chosen, as it has the best insulation coefficient λ of all different Pentane's in the gas phase. (Alternatives: ISO-Pentane and n-Pentane in continuous operations).

The composition of the used C-Pentane is shown on the following foil (foil 1).

A first C-Pentane foamed refrigerator has been exposed by LIEBHERR at Düsseldorf's Plastic fair in Autumn 1992.

In 1992, after various tests of all kind, we decided to phase-out in both our factories

CFC R11 by HC Cyclopentane
CFC R12 by HFC R134a

and the procedure was finalised and the conversion 100% executed in April 1993 with a max. standstill of one week in each factory.

Being the first one worldwide to undergo such a project was an immense task, combined with the short realisation period of only 5 months. It was a pioneer task.
Unfortunately at that time the R600a refrigerant technology wasn't mature, that is why we had to change to R134a first.

But in parallel to this development, we already concentrated on further improving, and the first refrigerator with HC R600a as refrigerant was launched shortly before, in February 1993.

Because of the direct greenhouse potential (GWP) occurring with R134a, this refrigerant has come under such pressure even before its generalised usage, that an alternative had to be found as quickly as possible, which has (practically) no direct effect on the earth's atmosphere, but which has thermodynamic properties at least equal to those of R134a, so that it does not adversely affect the indirect greenhouse potential (altogether known as TEWI-Total Equivalent Warming Impact).

REFRIGERANT CONVERSION

Hydrocarbon refrigerants, which produce the best conditions in this respect, have been known for decades, but have never been properly considered because of their flammability. Thanks to the consistent PR efforts of an environmental organisation this flammability was suddenly accepted with the best result that nothing now withstands the use of a Hydrocarbon refrigerant. LIEBHERR therefore made an extensive evaluation to find the best Hydrocarbon refrigerant.

To determine the optimum Hydrocarbon refrigerant, trials were carried out in the context of the test series on the three relevant appliance groups:

1- single-temperature refrigerator
2- refrigerator with freezing compartment and
3- freezer (including no-frost)

Our conclusions from tests carried out:

R600a (Isobutane) is the optimum refrigerant for all domestic refrigerators and freezers (foil 2).
The results in energy-consumption and performance are the same or better as with the refrigerants R12 and R134a.

Through appropriate measures, like

- optimising the foam system with C-Pentane
- adding insulation thickness
- optimising the cooling circuit components for R600a
- using HE (high efficiency) compressors

we achieved with Cyclopentane and Isobutane refrigerators up to 10% lower energy-consumption compared with R11/R12 CFC's (foil 3).

Basically we can say that with R600a we have a refrigerant for which there is no better alternative in the medium term, as it has very good thermodynamic properties and makes practically no direct contribution to the greenhouse effect (foil 4).

From the security point it is now clear that also no-frost units can be changed to R600a.

Just a short time after the introduction of the HFC refrigerant R134a, a complete change of refrigerant is now imminent in the German and thus also in the European domestic refrigerator sector.

This last change is gladly accepted by our after sales service people, as technical problems with HC are much more inferior to the ones faced with R134a (roughly 50% less).

Therefore, where has not yet been a conversion to R134a (e.g. developing countries), a changeover from R12 directly to R600a should be considered, without going via the difficult and costly route of R134a.

Up to now, LIEBHERR has converted more than 70% of the production to the refrigerant R600a.

Thus LIEBHERR was the first manufacturer worldwide phasing-out CFC's and HFC's on its total production in 2 factories. This technical conversion had been approved and certified by the German TÜV-Südwest (a neutral safety inspection agency) that later on certified the conversion of all other German manufacturers too. Since April 1993 LIEBHERR has worked without any incident and has produced nearly 3 million refrigerators/freezers with C-Pentane and up to 1 million with Isobutane. During this period LIEBHERR has acquired a unique experience in this implemented technology which is steadily improved in day to day business.

For LIEBHERR, at this moment with conversion of the entire production to C-Pentane/R600a, the problems of environment, which are resulting from direct influence of the materials, are solved.

Furthermore, we are working to reduce the indirect damages of the environment caused by the production of energy for the use of the refrigerators and freezers (GWP/TEWI).

WORLDWIDE PHASE-OUT OF CFC'S

The fixed deadlines by the Montreal Protocol and its amendments are well known. Especially in Europe much shorter deadlines have been set up by national rules and laws.

These regulations enforced by national consumer organisations and Greenpeace led the industry to accelerated new developments and it happened in Germany that the HC-technology started in 1992 its success story. Initiated by LIEBHERR as the first, the C-Pentane foam started its introduction into refrigerator manufacturing and by the end of 1993 all German manufacturers had followed or even committed themselves to this change. In the meantime all important European manufacturers have changed to C-Pentane that has become a normal and up to date technology.

After some time of hesitation, other countries like Japan, New Zealand, Australia, Turkey, etc. followed.
Only the USA and Brazil have not yet accepted C-Pentane as a mature technology, mainly due to national constraints.

As to the use of R600a, initial acceptance started in Germany, initiated by Foron and LIEBHERR. Nowadays, all German manufacturers have committed themselves to R600a even for NO FROST models. In other European countries like Italy, Austria, UK, Sweden, Switzerland major manufacturers have started to introduce series of R600a models.

Japan, in general not so committed to the Montreal aims, is still hesitating, not willing to apply R600a to their NO FROST system.
On the other hand, compressor manufacturers like Americold / USA; Embraco-Siccom / Brazil; Matsushita / Japan; Goldstar / Korea started to produce R600a compressors in larger scale.

SITUATION IN ARTICLE 5 COUNTRIES

In the last years a lot of different alternatives for R11 and R12 had been checked and tested, not only in Europe, Japan and USA, but also in China or India e.g. These substances had been mainly R141b for the foam and R134a as refrigerant, R152a, R22/R152a blends and Hydrocarbon blends.

In most countries, HCFC-141b will not be selected because it only offers a temporary solution and is not so good compatible with cabinet liner material. Cyclopentane however has zero ODP and low GWP and has been successfully implemented in Europe. It is compatible with materials currently used in the refrigerators and has been determined to be durable and suitable for use in domestic refrigerators. Cyclopentane is generally cheap and can be made available in most countries on the basis of locally available basic materials.

The manufacturing technology for use of Cyclopentane is mature and the control systems have been established so that this technology may be applied even in developing countries with strict processing regulations and production staff training. In order to assure an adequate margin of safety, the safety standards for any project should be equivalent to those in place in Europe.

The performance of R134a, R152a, R22/152a blends, pure Hydrocarbons and Hydrocarbon blends was investigated. As to the refrigerants Isobutane was selected as the best substitute refrigerant, because it has zero ODP and negligible GWP, and offers a final conversion, unlike R134a. Use of Isobutane as a refrigerant has been successfully commercialised in Europe. Isobutane is compatible with materials currently used in refrigerators and compressors, unlike R134a, which requires more important changes to the compressor and lubricant.

Isobutane can be made available at reasonable prices in most countries like Cyclopentane.

In consideration of the fact that some of the leading European manufacturers, like LIEBHERR, Bosch-Siemens and Electrolux have announced to convert their entire production to Isobutane by end of 1996; such step seems now more and more feasible for other manufacturers and countries too.

The longtime hesitant MMF is considering HC's as viable alternative and a high ranking MMF/EC delegation has visited the German LIEBHERR factory as the first Hydrocarbon applier worldwide in January 1995. Since end of 1994, C-Pentane conversion projects are constantly approved by the MMF, among others for Iran, Argentina, China, Cameroun, Bulgaria, Egypt.

At the Executive Committee meeting in Montreal in March 1995 the first complete Hydrocarbon conversion project had been approved, including Cyclopentane and Isobutane equipment and conversion of some refrigerator models to R600a.

This pilot project had been presented jointly by Germany and the USA in cooperation with the P.R. of China and will be carried out by LIEBHERR to switch over a famous Chinese manufacturer with LIEBHERR-technology.

The C-Pentane conversion had already been commissioned in June 1995, Isobutane will follow in early 1996.
In the meantime other complete Hydrocarbon conversion projects (C-Pentane and R600a) have been approved, two in Argentina and two more in China.
In China the first full HC-refrigerator/freezer combination was sold to the mar

ket in September 1995. The model had been converted with the assistance of LIEBHERR and 6'000 appliances have been sold until end of 1995.
A second manufacturer has followed in Autumn 1995.

These examples show the growing interest for the HC-technology in article 5 countries, provided they get the appropriate assistance.

The assistance which these countries will need are in general :

a. conversion and partial replacement of equipment, used at present
b. delivery of new machinery and equipment
c. installation, commissioning, trial operation and test run
d. training at the technology supplier's plant and on the job
e. safety precautions and systems according to the highest available standards

Most Article 5 countries are now ready to convert to C-Pentane as foam blowing agent, but are still not sure, whether to change to R134a first or directly to R600a.

As these countries are eligible for funding from the Montreal Multilateral Fund (MMF) they may ask through their concerned governmental agencies for the Funds support in carrying out feasibility studies to find out the best suitable solution.

The World Bank and the German GTZ are ready to finance such studies that may result in the formal request for MMF-funding to the Executive Committee of the Multilateral Fund for the implementation of the Montreal Protocol.

Since more than 17 years LIEBHERR has successfully executed and operated various projects in countries all over the world implementing LIEBHERR technology for local production of refrigerators and freezers.

LIEBHERR is also prepared to share its unique experience in Hydrocarbon technology with co-operation partners all over the world.

Any project executed by LIEBHERR will be according to German safety standards.

USE OF SYNTHETIC AND NATURAL FLUIDS IN COMMERCIAL REFRIGERATION APPLIANCES

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USE OF SYNTHETIC AND NATURAL FLUIDS IN COMMERCIAL REFRIGERATION APPLICATIONS

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SUMMARY

Refrigeration technology plays an important role for safety and health of the world's population. Especially the preservation of food is vital for the stability and economic growth all over the world. Refrigeration technology provides the technical aids to chill food following the cold chain without any interruption, starting at production, coming to transportation, finally storage, sale and storage at the consumer's home in a refrigerator.

Other applications include air-conditioning systems improving the comfort of human beings in private as well as for commercial purposes and also industrial processes where refrigeration is used e.g. for recovery of expensive or environmentally unacceptable substances.

This paper highlights the refrigeration technology options based on natural fluids newly redeveloped in Europe as compared to technology options based on continued use of still halogenated substitutes for CFCs, such as CFC-12 and CFC-502. Cost effective natural fluid based technical options in commercial refrigeration applications and in air conditioning have been launched on the market or will become available in the near future. This paper will also discuss present changes in the sectors of heat pumps and air conditioning systems due to the fact that those and commercial applications often have similar or equal components and a similar layout.

INTRODUCTION

The CFCs used so far in commercial refrigeration, in particular CFC-12 and CFC-502, have to be replaced in the near future. Some industrialised countries propagate the use of HFCs, such as HFC-134a as substitutes for the CFCs and HFCs. Some advantages and disadvantages of those expensive fluids manufactured mainly in industrialised countries in comparison to natural fluids are discussed in this paper.

For phasing out CFC-12, HFC-134a, which has a vapour pressure curve very similar to CFC-12 is proposed as replacement by its producers. Using HFC-134a, only some adjustments have to be made at the refrigeration cycle and to the compressor design, e.g. partially other elastomers. Similar to HFC-134a, several HFC mixtures were developed to replace CFC-502 and, later on, HCFC-22. These fluorinated substances do not damage the ozone layer, but have still very significant greenhouse warming effects. Nevertheless, severe disadvantages of these fluids in connection with their refrigeration oils and substances remaining from the production process are evident.

Natural fluid technology presently available offers similar, often higher performance than achieved with today's refrigerants, while at the same time continuing to use the same oils, components, elastomers and production processes like CFCs. This technology is the safe use of hydrocarbons for refrigerators, small commercial and air-conditioning equipment, while for larger air-conditioning systems and industrial uses ammonia is proposed.

Today hydrocarbons are already used in domestic refrigerators and increasingly in the field of commercial refrigeration, air conditioners and for heat pumps. It is expected that the field of applications will expand in the near future, especially for small compact units. The flammability of hydrocarbons has to be considered for production and lifetime of the appliance. To ensure safe operation, some design changes have to be incorporated in the design.

For applications with more than around 50 kW cooling capacity an alternative for the use of CFCs is the increased use of ammonia. The general know how concerning construction, servicing and operating of ammonia equipment is available world-wide. New technologies allow to use ammonia with techniques similar to those used with CFCs, improving the cost effectiveness also of small ammonia plants to the level achieved with HFCs or, in case of larger equipment, even further.

The manufacturers converting to hydrocarbons or ammonia choose long lasting alternatives to CFCs, being independent of high-tech manufactured or patented substances such as HFCs and the synthetic oils. These substances have to be purchased in industrialised countries while hydrocarbon fluids can be gained from refineries and ammonia from production plants for fertilizers, both located on all continents.

USE OF HYDROCARBONS IN COMMERCIAL REFRIGERATION APPLICATIONS

Present Situation

The successful application of hydrocarbons in the field of domestic refrigeration caused an increasing interest in natural fluids in refrigeration applications other than refrigerators. Presently, developments are focused to phase out CFC-12 and CFC-502, but also already HCFC-22. Those refrigerants were used in close to all refrigeration applications.

CFC-12 was used almost universally. The range of applications varies from large water chillers to refrigerators with small hermetic commercial equipment, automotive equipment and, especially in hot climates, all kinds of transport and storage equipment in-between. CFC-502 was mainly used in commercial units for frozen food. HCFC-22, scheduled to be nearly phased out in industrialised countries until 2020, was mainly used in air-conditioning equipment, where its high capacity has the advantage of small size and cheap components, while certain disadvantages are not critical.

Which Hydrocarbon should be used?

Fluid properties
Small compressors, meaning compressors with a low swept volume, are often cheaper, but also less efficient than large compressors. With increasingly smaller compressors, cost advantage and efficiency decrease overproportional. Very small compressors are not significantly cheaper than those having twice the size, but significantly more inefficient. HC-600a, isobutane, is a refrigerant well used in small applications up to 500 W capacity, such as refrigerators, because it requires a relatively high displacement compressor, which is already cheap but still efficient. Nevertheless, if the desired capacity is higher than approximately 500 W, the use of another hydrocarbon refrigerant is economically more suitable: The use of HC-290, propane.

Based on the positive experiences with isobutane as a refrigerant in domestic refrigeration also other small compact units have been developed. At present some units with isobutane as refrigerant with approximately 300 W cooling capacity are available. These units are plug-in units which are hermetically sealed and thoroughly checked for leakage by the manufacturer.

Not only for larger capacities but also for low temperature applications and heat pumps the natural refrigerant propane, HC-290, shows excellent thermodynamic and thermophysical properties. Like isobutane propane is flammable. Propane is an advantageous substitute for HCFC-22 due to its similar temperature-pressure behaviour, but also for CFC-502 due to the low compressor discharge temperature. The advantages concerning the use of standard refrigeration oils and, such, the absence of problems related to a high humidity content of ester oils are similar to those of isobutane. The work quality achieved with CFCs is sufficient for the use of propane.

For the widely used, cost effective single-stage refrigeration systems, propane allows higher temperature differences between evaporation and condensation than possible with ammonia or HCFC-22 because of its low compressor discharge temperatures. For this reason, propane is also a substitute for CFC/HCFC-502 in a single-stage system while a replacement with HCFC-22 or ammonia would require an expensive two-stage compression system.

The refrigeration oil - an important aspect for refrigerant selection

Seemingly a suitable replacement for CFCs, the new HFC substances required the development of a totally new, synthetic refrigeration oil for compressor lubrication. Such a refrigeration oil, partly circulating with the refrigerant in the refrigeration cycle, is extremely important for the lifetime of the system. All the oils which have been developed for HFCs are expensive, not compatible with oils used in the past and with HCFC-22, and highly hygroscopic. At the same time, the presence of water in the oil causes chemical breakdowns and formation of new substances in the cycle, leading to a significantly shorter lifetime of the compressor. Thus, the presence of liquid or vapour phase water has to be avoided in the cycle.

This problem requires a reorganisation of the production to ensure that the compressors containing the oil as well as all other parts are highly dried after manufacturing and sealed airtight, to be opened only directly before assembly. In addition, exceptional attention must be paid to the cleanliness of parts in case of utilisation of capillary tubes as expansion devices or at low temperature applications; in these cases, severe difficulties like capillary tube blocking have been reported because HFCs are very sensitive to contamination by chemicals from production or service. The fulfilment of most of these requirements can not be monitored by some kind of test equipment, but depends highly on the responsible acting of each person taking part in the production process of the components and the product. If a minor mistake has been made it may not be noticed before the customers lay claim to the warranty a few month later.

These difficulties increase further in case of service. If the refrigeration cycle is opened for service purposes, the oil has to be removed completely, which is virtually not possible without removing the compressor from the cycle and opening it - a time consuming operation.

In addition, the service has to use a high-quality low vacuum pump with a special vacuum pump oil, and the new oil has to be taken from containers sealed by the oil manufacturer until service. Oil containers opened hours before use, e.g. at the prior service location, can not be used because of the rise in humidity content. Considering the fact that this will require significant investments into a new vacuum pump, longer working time for the service and higher costs for and different handling of the refrigeration oil, as well as the fact that the customer has no means to control the quality of work, it has to be expected that the service will often not be carried out in the quality required. This may very well lead to compressor replacements as often as every year to keep the refrigerator running. The cost for each household as well as for the economy are very significant, at the same time decreasing the trust of the consumer into the manufacturer whose product he originally purchased.

A second alternative for the replacement of CFCs such as CFC-12 or CFC-502 is the use of hydrocarbons. Discussed is the use of isobutane (HC-600a), propane (HC-290) and their mixtures. These substances are hydrocarbon derivatives produced in petrochemical plants. The technology with hydrocarbons as refrigerants is compatible to the CFC technology. This means that hydrocarbons are miscible with the same oils and can be sealed with the same elastomers. The hydrocarbons and their oils are not hygroscopic and not especially sensitive to contamination by chemicals from production or service.

Other aspects
Propane is fully compatible with most materials used with CFC-12 or HCFC-22. As stated above, the same type of refrigeration oil can be used as with CFCs. However, due to the high solubility of hydrocarbons, in some cases it might be necessary to chose a refrigeration oil with the next higher viscosity class.

Especially when changing from CFC-502 or CFC-22 to hydrocarbons, no specific adjustments are necessary to most components. Usually, the same heat exchangers can be used without a recalculation. If converted from HCFC-22 to propane, the filling of the thermostatic expansion valve can be left, but an optimised filling is recommended. Using capillary tubes, length and diameter have to be optimised.

To ensure product safety, leakage and ignition sources have to be minimised. To reduce the hazards, potential leak sources, such as joints, should not be placed in the space to be cooled. To avoid the presence of a flammable mixture next to an ignition source, electrical switches with IP54 protection should be used. This will minimise gas exchange between switch housing or cabinet and its environment. Additionally, the refrigerant charge of the appliances should be minimised. This can be realised by compact design. Referring to component changes, the compressor displacement has to be adapted to the refrigerant to achieve similar capacity. Furthermore, it is highly recommended to use piston rings to increase the efficiency.

Presently, all manufacturers producing hydrocarbon systems other than refrigerators use standard compressors, e.g. CFC-22 compressors for HC-290.

In the following, examples for systems existing on the market are given.

Systems on the market

Heat pumps

All German heat pump manufacturers are in the process of switching their complete production to HC-290 as a working fluid. In general, the producers achieved higher efficiencies than with HCFC-22 or other halogenated substances, while at the same time the condensing temperature could be increased because of the low discharge temperatures of propane. The variety of types in production consists of hot tap water heat pumps with 1.5 to 2 kW capacity and heating systems with 5 to 35 kW capacity. Also, heat pumps for dehumidification of indoor swimming pools are equipped with propane.

Room air conditioners

An Italian and a German manufacturer produce air conditioners with propane as working fluid, having a capacity between 1.9 kW and 2.4 kW. The Italian producer, DeLonghi, is the European market leader for small air conditioning systems. While presently only compact units are available, DeLonghi announced split systems using hydrocarbons for 1996. These units are stored and sold in warehouses, to be self transported and installed by the consumer.

Commercial systems

For purposes of commercial refrigeration only some systems are known to be developed so far. This is on the one hand due to the only recently available information concerning safety technologies which handicapped developments, on the other hand the numerous small enterprises do not announce the use of hydrocarbons on a large scale, thus never coming to the attention of the author.

Nevertheless, some examples are known, e g. a shop in the inner city of Frankfurt where the freezing room is cooled by propane in a split application. In this refrigeration plant with a charge of 2 5 kg propane a standard HFC-22 compressor and a standard HFC-22 thermostatic expansion valve are used. The safety equipment only consists mainly of a gas detector while all the electrical equipment is IP54 sealed.

Handling of equipment in the field

General

The lifetime of equipment in the field is often significantly higher than 20 years A huge amount of equipment is already in the field, using CFCs as working fluid. Also, the continuing use of HCFC-22 will cause significant amounts of installations with CFC technology. After the transition to replacements for CFCs, the CFC technology as well as its replacement will be both present in the field. Such, compatibility is highly desirable.

During system lifetime, usually several repairs of the equipment take place. The filling of the refrigeration system has often to be topped up or replaced in case of major accidents. Using two different refrigerants in basically similar equipment, the risk of mistakes like filling of the wrong refrigerant is obvious. The decision for a new refrigerant should reflect these difficulties severely.

Service

Repairs are carried out mainly by the so called unorganised or informal sector. This sector is usually formed by small enterprises. They have to work very cost effective, while at the same time the customer has no real means of quality control. The cost effectiveness also causes a limited time spent for training and knowledge gathering, and little inclination to purchase appropriate tools for specialised repairs if the tools already possessed still seem to work properly.

If it is decided to use HFC technology as the main alternative for CFCs, it has to be seen that it will be virtually impossible to train the whole unorganised sector in the handling of those sensitive refrigerants, lubricants and equipment with respect to cleanliness, humidity, etc., as well as convince them to purchase new vacuum pumps, handle the oil properly (meaning e.g. never use an oil can with an open lid, no matter what the content is) and so on. This difficulty is increased because of the fact that the negative effects of improper handling are only evident after months.

On the other hand, the service technicians are already trained in the use of flammable gases due to the use of their soldering torches. And mistakes they make will affect them directly, causing appropriate handling of hydrocarbon refrigerants.

Since HFCs are much more sensitive to improper handling than the hydrocarbons, and according to the hazard humidity constitutes for the lubricants required for HFCs, hydrocarbons are the better choice for commercial refrigeration equipment in developing countries.

Drop in and retrofitting

The availability of CFC-12 and CFC-502 for repairs of applications using these refrigerants will decrease in the near future, causing the need for other refrigerants to be charged.

In general, a refrigeration system is designed for a specific refrigerant. This relates to the dimensions of compressor and heat exchangers as well as the used material. If the original refrigerant is exchanged and replaced by another one, it can be distinguished between drop in and retrofit. Drop in means the exchange of the refrigerant without any and retrofitting with some system modifications.

HFCs cannot be used for drop in of CFC applications because of the immiscibility with the lubricant, insensibility to contaminants, missing material compatibility, etc. A charging with HFCs will very likely result in severe damage of the application, unless an extensive flushing procedure has been carried out. In case of small and medium sized hermetic compressors, which usually do not have an oil drain plug, the compressor often has to be removed from the cycle and opened.

In contrast, hydrocarbons can relatively easy be used as a replacement for CFCs. For CFC-12, a mixture of isobutane and propane (approximately 50% (mass) propane) has nearly the same refrigerating capacity as CFC-12. For the replacement of CFC-502, HC-290 can be used if an (approximately) 5 to 10% decrease of capacity can be accepted. The discharge temperature of HC-290 is even lower than that of CFC-502. If the same capacity is necessary, a mixture of propane and ethane is possible. Those mixtures are commercially available. With those mixtures, a similar refrigerating capacity with a slightly lower efficiency due to less favourable heat transfer values can be achieved.

Nevertheless, in the case of hydrocarbons used as drop in refrigerant for CFCs, the safety requirements of the application have to be considered. Most likely, some components have to be replaced to ensure that no ignition sources are present at exposed spaces, e.g. in a limited space to be cooled. The switch box or fuse box has to be replaced by a box with IP54-protection, where all switching elements are located. Klixxon devices mounted outside the compressor have to be sealed, e.g. using silicone. Nevertheless, in some cases, the use of hydrocarbons as replacements in old equipment will not be appropriate due to safety considerations.

Safety

Hydrocarbons like propane and isobutane are flammable. Therefore, the safety aspects of applications with hydrocarbons have to be considered carefully. The main objection to the use of hydrocarbons as refrigerants is the flammability of these fluids, whereas the alternative HFCs are either not flammable or mixed in a way that their flammability is suppressed - but demixing might still cause in very rare cases the formation of an explosive mixture. In addition, if the pressure is higher than ambient pressure, HFCs can also form explosive mixtures with air, e.g. HFC-134a at approximately 1 bar above atmospheric pressure.

Safety concerning flammability aspects must be considered for the hydrocarbons and their mixtures during production, distribution, use, recovering, and recycling. The safety principle for the use of hydrocarbons is very simple if one reflects the basic idea: The coincidence of the necessary conditions for an accident a flammable mixture of air and working fluid and an ignition source has to be avoided.

To generate a flammable mixture in a room with around 16 cubic meters (2,5 x 2,5 x 2,5 m) 670g isobutane or propane are necessary assuming even dispersion. Typically a 165 litre domestic refrigerator would contain about 30g, with some 10g remaining in the oil in case of a major rupture. The room air conditioners presented above contain approximately 300 to 500 g of hydrocarbons. Typical leak rates vary from 0.5g/year and 3g/year for products manufactured in a highly sophisticated way in large factories (refrigerators, air conditioners) and around 100 g for very poorly manufactured applications.

Additionally, it must be taken into account that refrigerators are often repaired in developing countries, either in contract workshops or in free workshops. To avoid the risk of explosions during faulty repair or resulting from faulty repair, the following measures are proposed:

* Reducing the delicacy for faults,

* Leak testing as part of routine maintenance,

* Training programs for technicians of factory workshops and the those of the unorganised sector during transition period.

At the moment, there are only few commonly agreed guidelines for the design of applications. Presently, Germany is the only country world-wide possessing approved safety standards for hydrocarbons in applications other than domestic refrigerators (DIN 7003). European standards are presently under preparation (EN 378 (available as preliminary print), EN 60335, part 40 (yet not available)). Also several national standards are under preparation, which often use the DIN 7003 as example. Once the safety standards are defined, it is expected that the market share of hydrocarbon refrigeration systems will increase significantly.

USE OF AMMONIA IN COMMERCIAL REFRIGERATION APPLICATIONS

General

Ammonia has been a well known refrigerant in large scale industrial applications for more than 120 years. The know how concerning the technology is widely dispersed, in industrialised as well as in developing countries. Nevertheless, up to recently it has nearly never been used in air-conditioning applications or small refrigeration plants, despite the fact that ammonia has excellent thermodynamic and thermophysical properties,
high efficiency in most temperature ranges, no ODP, no GWP,
low refrigerant cost, great tolerance to water contamination and
strong smell, so ammonia is easily detectable at very low concentrations (5 ppm).

The disadvantages which lead to the ignorance of ammonia for the systems mentioned above are especially

- toxicity at low concentration in air,
- flammability at high concentration in air,
- no compatibility with zinc or copper or copper containing alloys, high discharge temperatures.

For large systems, the disadvantages of ammonia mainly concern safety; for small systems, there are presently additional cost disadvantages.

The actual toxicity of ammonia is usually not a major concern; the smell is noticed by man at concentrations as small as 5 parts per million (ppm). At the same time, the threshold limit value, which should not be exceeded for everyday exposure, is 50 ppm. Ammonia is unbearable for man at 500 ppm, while its acute toxicity starts at 2500 ppm and the flammability at 15 vol%. Obviously, nearly any hazard announces itself in far advance, making ammonia actually a very safe refrigerant concerning direct hazards.

Unfortunately, there is an indirect hazard caused by use of ammonia in public areas: Panic. Heavy ammonia concentrations might cause (unnecessary) panic among those which are not familiar with the smell. The main focus of the safety measures is therefore to avoid a fast increase in ammonia concentration in public areas up to or above the panic level.

Such, the safety rules for ammonia plants are very simple: No parts of a plant in direct contact with the public, and installation of systems to hold back significant ammonia amounts in case of a major rupture. While the former causes the need for indirect systems - which are per definition always present in case of water chillers -, the latter leads to housings around the systems, often combined with a water tank. The water in such a tank allows to solve a significant amount of ammonia completely. 50 litres of water can solve up to 50 kg of ammonia. With such an amount of ammonia, systems with up to 1.4 MW can be built.

Applications

Air conditioning

Air conditioning of large buildings is often performed by centralised air conditioning systems with capacities above 700 kW, which use cool water circulating through the building to distribute the cooling capacity. In the past, often centrifugal chillers were used, utilising mainly CFC-11 as refrigerant. Because of the toxicity concerns connected with HCFC-123, the existing old CFC-11 equipment is often not converted to HCFC-123 but replaced by new equipment, using either HCFC-123 or HFC-134a. If this is the case, the use of ammonia is a very attractive alternative because instead of replacing the old CFC-11 by a new centrifugal chiller, an ammonia plant can be installed. These ammonia plants can be placed as rooftop units, as stand-alone units next to the building or in the basement; in this case a duct for forced ventilation in case of major ammonia emissions should be installed.

Supermarkets

Presently, the use of ammonia plants for cooling of medium and large supermarkets is increasing. The reasons are the introduction of secondary refrigerant (brine) systems into the market, which have several advantages. These brine systems distribute a cold secondary fluid, e.g. a water-glycol mixture to the different cooling or freezing cabinets. While the brine is increasing its temperature when running through the heat exchanger in the cabinet, it is cooled down in the evaporator of a centralised, pre-fabricated refrigeration plant which can be located in a machine room inside or outside the market.

The advantages of those systems are, on the one hand, low refrigerant emissions of the refrigeration plant because of compact design and quality control during the manufacturing process. On the other hand, the control of secondary fluid systems is much easier than the control of direct expansion systems when numerous cabinets have to be cooled. Third, the brine system can often be constructed by personnel with a low level of training, making the construction cheaper and easier to organise. Using a secondary system in supermarkets, ammonia systems can easily be applied to generate the necessary cooling capacity, because all ammonia containing parts can be placed outside the public shop area.

Recent technical developments

Recent developments introduced copper-free aluminium alloys as material for tubing and fluxing material for these aluminium alloys. Those allow with soldering of parts and bending of the pipework a manufacturing process similar to those of CFC plants instead of the so-far used ammonia technology of welding steel pipes, thus reducing the costs of installation.

Ammonia systems could not be operated in a self-controlled manner due to the immiscibility of the refrigeration oil with ammonia. In 1992 a soluble oil based on polyalkylene glycols (PAG) was introduced into the market which enables an oil return to the compressor in the same way as CFCs do. In the meantime, different soluble oils for ammonia from several manufacturers are on the market.

The acceptance of ammonia in the public can be increased as well as the demand for safety equipment can be reduced by a minimised refrigerant charge and hermetically sealed system. A significant reduction of charge is enabled by dry expansion evaporation. A basic requirement for this is the application of a soluble oil. At the same time, the new technology of soluble oils allows the use of newly developed ammonia resistant plate heat exchangers as evaporators and condensers, which reduces again system refrigerant charge.

Initiated by the increasing interest in ammonia several compressor manufacturers developed new ammonia compressors. In the recent years semihermetic and hermetic compressors have been developed.

MARKET SHARE

General

Those refrigerant manufacturers who could produce HFCs promoted all kinds of CFC control, while at the same time using their immense public relation possibilities to advertise HFCs as the only alternative to CFCs and HCFCs. At the same time, the process of regulations tightening up constantly lead to concerns among OEMs and customers: What would happen if they choose an alternative to CFCs which might be obsolete in the near future? Who would repay their investments into new refrigeration and production equipment? Naturally, these questions were first asked in case of major investments. Thus, the water chillers with large refrigeration capacities, using HCFC-123 and HFC-134a as alternative refrigerants, came under market pressure. An alternative for HCFC and HFC technology was already present: The ammonia technology, for 120 years established for large refrigeration capacities in industrial and food processing applications, had only to be supplemented by safety features, such as a minimisation of filling mass, gas tight housings and water tanks to solve escaping ammonia in.

Hydrocarbons

For the same reasons, first researchers, then industrial manufacturers of refrigeration equipment started to look into the so called natural refrigerants as alternatives for CFCs. Due to the state of the art present in small refrigeration systems - a non flammable working fluid - hydrocarbons were first not considered.

But other natural alternatives failed as short term solutions because of necessary investment costs for conversion of production and different equipment shortcomings. Thus, hydrocarbons, requiring only well known technology inside the refrigeration cycle, were reconsidered.

The announcement of the use of hydrocarbon technology by the German refrigerator manufacturer Foron, heavily supported by Greenpeace, forced other, larger refrigerator companies to proof their ability to develop similar models; the sale success of the Foron refrigerator forced the marketing of those models. Surprisingly enough, the marketing was a major success for those refrigerator companies which were ahead of the competition. In 1993, all Western European refrigerator companies selling to the German market started to convert their production step by step from HFCs to hydrocarbons.

This movement to hydrocarbons caused OEMs in other fields to reconsider their attitude towards HFCs. The first were some specialised OEMs for certain types of commercial refrigeration like beer coolers which advertised equipment charged with hydrocarbons already in 1993. In early 1994, the German manufacturers of heat pumps announced that they would start with the production of equipment charged with HC-290 soon, which they did in spring. The so far latest product group are air conditioners which use HC-290 as working fluid; those are available on the market since spring 1995.

The development for refrigeration applications other than household refrigeration is divided into two directions: On the one hand, the development of hydrocarbon applications to larger refrigeration capacities can be noted; on the other hand, the ammonia applications tend to large air-conditioning systems, but also to medium capacity systems for commercial use with secondary systems.

The use of hydrocarbons in household refrigeration caused also manufacturers of other refrigeration applications to consider those refrigerants. While several small enterprises started soon after the refrigerator industry to promote hydrocarbon systems, e.g. for beer cooling, the first major use of hydrocarbons in refrigeration applications was the use of heat pumps, produced on an industrial scale. Since mid of 1994, heat pumps with hydrocarbons are available on the market in a large scale. The main technical difference to refrigerators is the amount of filling, which is up to 2 kg of HC-290. In this year, the market share of the hydrocarbon heat pumps for space heating is close to 100% in Germany, a market with approximately 1500 space heating heat pumps per year.

Other refrigeration industries do also work on hydrocarbon technology: In the meantime, a system for cooling of switch cabinets and also systems for drying of pressurised air have been developed, while at the same time the amount of producers of small, customised refrigeration systems for the commercial market with hydrocarbons as working fluids is increasing.

Ammonia

New applications of ammonia as working fluid are supermarket applications and centralised air-conditioning systems. In case of the supermarket systems, the necessary development of suitable brine systems to distribute secondary refrigerants slowed down the development. Presently, there are 7 supermarkets in Luxembourg, 4 in Switzerland, 2 in Italy and 2 in Germany whose medium and low temperature display cabinets are cooled by ammonia plants.

The use of ammonia in air-conditioning systems is now a widespread technology. Presently, the market share of large air-conditioning systems with ammonia is reported to be close to 100% in Sweden and Luxembourg and around 30% in Germany and Switzerland. In general, the ammonia market for air conditioning is well developed in Middle and North Europe. In the Southern countries of Western Europe as well as in Great Britain and France so far only small market shares of ammonia plants in large air-conditioning systems have been achieved.

CONCLUSIONS

Natural refrigerants in general and hydrocarbons in particular are suitable for refrigeration purposes in industrialised as well as in developing countries. The safety issues, which have to be considered, can be solved with technology and know how available for decades.

The refrigerants are cheap and accessible, the know how for their handling is available. Natural fluids have proven to perform similar or better than any other alternative in a refrigeration cycle.

The technology to be used is proven. Several manufacturers selected this technology for their large scale production. Among those are subsidiaries of the world's leading refrigeration companies.
On the other hand: The other alternative for the use of CFCs are HFCs. For the use of CFC-502 and HCFC-22, there is no really convincing long term HFC solution available yet. This technology requires a high level of organisation in production and service.

Even if the required quality in the production processes can be achieved in the factories in developing countries, a sufficient level of quality in the manufacturing of the various component suppliers is doubtful, whereas it is certain that the unorganised service sector will not be able to fulfil all the requirements of proper operation.

Thus, it seems to be very worthwhile to consider natural fluids in general and hydrocarbons for refrigerators and small hermetic applications in particular as an alternative option to the HFC technology so loudly supported.
Cui bono?
(Who benefits?)

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HYDROCARBON REFRIGERANTS: PROPERTIES, PURITY AND SAFE HANDLING

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ECOREFRIGERATION
CONFERENCE ON HYDROCARBON FLUIDS IN DOMESTIC AND COMMERCIAL REFRIGERATION APPLIANCES

Hydrocarbon Refrigerants: Performance, Purity and Safe Handling.

Jane Gartshore, Cool Concerns, UK
and
Jack Buswell, Calor Gas, UK

Introduction

Considerable experience has been gained in the UK in the training of refrigeration technicians and in the safe application of hydrocarbon refrigerants in many different domestic and commercial refrigeration and air conditioning applications. This paper is based on the training manual produced for the UK (and Australian) markets. It covers:

- Introduction to the hydrocarbon refrigerant range from Calor Gas
    - physical properties
    - environmental effects

- Performance of hydrocarbon refrigerants
    - operating conditions
    - capacity and efficiency
    - charge quantity
    - use in new and existing systems

- Handling of hydrocarbon refrigerants
    - general safety issues
    - charging
    - leak detection.

Introduction to Hydrocarbon Refrigerant Range

Hydrocarbons are, in general, very good refrigerants and are becoming more widely used in many applications. They have advantages over halocarbon type refrigerants:

- zero ozone depletion potential

- very low global warming potentials

- good performance characteristics.

The table below summarises the Calor Gas hydrocarbon refrigerant range.

Refrigerant	**Boiling point, °C at atmospheric pressure**	**Composition**	**Application**
R600a (Care 10)	-12	iso-butane	New domestic equipment
Care 30	-31 5	Zeotropic hydrocarbon binary blend	Drop-in replacement for R12 (and R134a)
R290 (Care 40)	-42	propane	New high, medium and low temperature equipment
Care 50	-49	Zeotropic hydrocarbon binary blend	Drop-in replacement for R22 and R502

R600a

R600a is pure iso-butane (also known by the trade name Care 10), and is primarily for new domestic type equipment It operates at significantly lower pressures than R12 or R134a, so its use requires modifications to components It is not designed to be used in existing R12 or R134a systems

Care 30

Care 30 is a hydrocarbon blend, developed to replace R12 in existing installations with minimum modifications to the system Its major use will be in domestic refrigerators, small commercial systems and transport refrigeration and air conditioning applications Whilst Care 30 has been formulated as a replacement for R12 it can also be used in R134a systems

There are several alternatives for R12, but Care 30 has advantages

- superior energy efficiency
- similar capacity to R12
- compatible with R12 system components, including oil
- no system modifications necessary i e no change of compressor, evaporator,

condenser, TEV etc

Care 30 is a purified blend of propane (R290) and iso-butane (R600a), with a boiling point of -31 5°C at atmospheric pressure The blend has been developed to produce a refrigerant with a capacity as similar to R12 as possible This ensures it is a useful replacement for R12 in existing systems It can also be used in new systems

R290

R290 is pure propane (also known as Care 40), and is primarily for use in new equipment which would traditionally have used R22 or R502 (or ammonia) If used in existing R22 and R502 systems, it may not give the same performance as the R22 or R502, and modifications many be required.

Care 50

Care 50 is a hydrocarbon blend, developed to replace R22 and R502 in existing installations with minimum modifications to the system It can also be used in new systems It has a boiling point of -49°C at atmospheric pressure The blend has been developed to produce a refrigerant with a similar performance to R22 and R502 This ensures it is a useful replacement for these refrigerants in existing systems

The most important properties of Care 50 as a refrigerant are listed in the following table, with data for R22 and R502 given as a comparison

The importance of the correct blend and purity.

The hydrocarbon refrigerant range has been developed to give specific operating conditions and performance Commercial propane and butane **must not** be used These fuel grade products are of variable composition and contain impurities, including moisture, which would significantly reduce the reliability and performance of the system, and would lead to premature failure

Refrigerants should be produced to the ARI 700 standard for new refrigerants (Air Conditioning and Refrigeration Institute - USA) This specifies very low levels of impurities (e g moisture, solids, acids) allowed in virgin refrigerant

In the cases of Care 30 and Care 50 the blend composition is important Using a blend with a different composition may result in

- operation at different pressures and temperatures, which may be detrimental to system component performance and reliability,
- significantly lower capacities and / or efficiencies

Effect of hydrocarbon refrigerants on the environment.

Hydrocarbon refrigerants are natural substances with very short atmospheric lifetimes - weeks and months rather than 100+ years for CFCs. Once in the atmosphere they break down to carbon dioxide and water. Although carbon dioxide is a greenhouse gas, it is a very weak one. The significant effect of carbon dioxide on global warming is due to the very large quantities released through burning fossil fuels for power generation. The amount released by the use of hydrocarbons as refrigerants would be an extremely low proportion of the total.

Hydrocarbon refrigerants contain no chlorine or bromine and therefore have no ozone depletion potential. Their global warming potentials are related to the carbon dioxide produced when they break down in the atmosphere and are compared to other refrigerants in the following table:

Refrigerant	**GWP (500 year basis) ***	**ODP ****
R600a, (Care 10)	< 4	0
Care 30	< 4	0
R12	4500	1.0
R134a	420	0
R290, (Care 40)	< 3	0
Care 50	<3	0
R22	510	0.05
R502	4000	0.31
R404A	1400	0

* GWP (global warming potential) is relative to carbon dioxide = 1
** ODP (ozone depletion potential) is relative to R12 = 1

Other replacements for R12, R22 and R502 based on HCFCs and / or HFCs have global warming potentials of the same order as those for R134a and R404A.

TEWI.

The total equivalent warming impact (TEWI) is a measure of the total impact of a refrigerant in a system on global warming. Refrigeration systems can contribute twice to global warming.

- directly through emissions of those refrigerants which are greenhouse gases,

- indirectly through the use of energy generated by burning fossil fuels (which causes carbon dioxide emissions)

$$\boxed{\textit{TEWI} = \textit{direct effect} - \textit{indirect effect}}$$

The TEWI can be reduced by

- using a refrigerant which has a global warming potential which is as low as possible

- reducing emissions of that refrigerant,

- improving the energy efficiency of a system by using an efficient refrigerant as well as by implementing generic energy efficiency techniques and technologies

Hydrocarbon refrigerants virtually eliminate the direct effect because of their very low global warming potentials Improved energy efficiency also reduces the indirect effect

Tables of physical properties.

Property, metric unit, weight basis	**R600a**	R12	R134a	**Care 30**	R22	**R290**	R502	**Care 50**
Boiling point at 1 atmosphere, °C	**-11.8**	-29 8	-26 1	**-31.5**	-40 8	**-42.1**	-45.4	**-49**
Specific heat of liquid at 30°C, kJ/kg K	**2.49**	0 99	1 45	**2.54**	1 27	**2.80**	1 26	**3.01**
Specific heat of vapour at constant pressure at 30°C, kJ/kg K	**1.86**	0 62	0 86	**1.7**	0 91	**2.12**	0.69	**1.71**
Ratio of specific heats (C_v/C_p) at 1 atm , 30°C	**1.10**	1 136	1 118	**1.116**	1 18	**1.10**	1 13	**1.10**
Density of liquid at 30°C, Mg/m³	**0.545**	1 292	1 187	**0.517**	1 17	**0.484**	1 19	**0.475**
Density of saturated vapour at boiling point, kg/m³	**2.81**	6 3	5 3	**2.6**	4 7	**2.40**	6.2	**2.22**
Latent heat of vaporisation at boiling point, kJ/kg	**362**	165	217	**405**	233	**426**	172	**444**
Thermal conductivity of liquid at 20°C, W/m°C	**0.098**	0 07	0 08	**0.1**	0 09	**0.094**	0 068	**0.097**
Thermal conductivity of vapour at 30°C, 1 atm . W/m°C	**0.017**	0 010	0 015	**0.018**	0 013	**0.019**	0 012	**0.020**
Surface tension at 25°C, mN/m	**9.55**	8 5	8 4	**8.6**	8 1	**7.03**	5 44	**7.92**
Viscosity of liquid at 30°C, centipoise	**0.14**	0 19	0 20	**0.11**	0 15	**0.09**	0 17	**0.08**

Performance of Hydrocarbon Refrigerants

This section will outline the major points to be considered when applying hydrocarbon refrigerants

- operating pressures and temperatures,
- capacity and efficiency,
- temperature glide (where applicable),
- charge quantity,
- compatibility with system materials,
- application in new and existing systems

Like many of the new alternative refrigerants Care 30 and Care 50 are zeotropic blends - i e they do not behave like a single substance This introduces some differences in application and use In application terms this mainly concerns temperature glide in evaporators and condensers

Flammability also affects the handling of the refrigerant and, to a certain extent, the system design

Operating conditions

The graphs in figures 1 and 2 compare the pressure / temperature relationship of the hydrocarbon refrigerant range with traditional refrigerants

R600a (Care 10) operates with much lower pressures than the other refrigerants shown, and is designed for use in new systems

Care 30 is formulated to operate with similar pressures to R12 It can be seen that at evaporating conditions the pressure of Care 30 will be slightly higher than either R12 or R134a, and at condensing conditions the pressure of Care 30 will be lower Care 30 will therefore operate with a lower compression ratio, thus improving the operation of the compressor. The discharge temperature of Care 30 is similar to that for R12 and R134a at the same evaporating and condensing temperatures

R290 (Care 40) operates with similar pressures to R22 at evaporating conditions and slightly lower pressures than R22 at condensing conditions The compression ratio is therefore slightly less than for R22 The discharge temperature of R290 is less than for R22

Care 50 operates with similar pressures to R22 and R502, although it is closer to R502. The compression ratio of a system operating with Care 50 will be less than those for systems using R22 or R502. The discharge temperature of Care 50 is less than that for R22 or R502 at the same operating conditions

Figure 3 gives the pressure / temperature relationships for the range in tabular form

Temperature glide

As with all zeotropic blends, Care 30 and Care 50 have temperature glide The data in figure 3 shows the two temperatures (the bubble temperature and the dew temperature) corresponding to each pressure for these two refrigerants

The bubble temperature is the saturated liquid temperature (the temperature of the refrigerant when it is just pure liquid, but not subcooled)

The dew temperature is the saturated vapour temperature (the temperature of the refrigerant when it is just pure vapour, but not superheated).

When a zeotrope boils, the composition of the vapour may not the same as the liquid - the vapour could be richer in the component with the lower boiling temperature

At the start of the evaporator the temperature of the refrigerant will be higher than the bubble point because some of the refrigerant will already have flashed off during expansion As the blend flows through the evaporator its boiling point rises as the composition of the liquid phase changes The evaporating temperature will therefore increase as the refrigerant flows through the evaporator and more of the blend evaporates This is the temperature glide. **In practice it will not be as much as is indicated by the difference in the bubble and dew temperatures in the tabulated data and is in line with many of the other refrigerant blends now available.**

The same effect occurs in the condenser In this case the condensing temperature will decrease through the condenser.

There are other effects of glide which apply to **all** zeotropic blends

- ice build up on an evaporator **may** be uneven due to the change in evaporating temperature through the evaporator,
- when checking superheat, the temperature of the refrigerant at the exit of the evaporator should be compared to the **dew temperature** corresponding to the pressure,
- the composition of the blend may be different in the vapour state **The refrigerant should therefore always be charged as a liquid,**

- in non-hermetically sealed systems, differential leakage **may** occur, depending on the location of the leak in the system

Refrigerants with temperature glide are not best suited for use in systems with flooded evaporators

Capacity and efficiency of hydrocarbon refrigerants.

Care 30 and Care 50 have been formulated to replace CFCs / HCFCs in existing systems and therefore have very similar performances although they can also be used very successfully in new equipment R600a and R290 are primarily for new equipment

The graph in figure 4 compares the required compressor swept volume for R600a and R12 at identical evaporating temperatures This shows that the compressor requires a greatly increased swept volume to give comparable capacity It would need the same size motor as a compressor designed to be used on R12

Care 30 has been formulated to give similar capacity to R12, and practical testing in both the laboratory and in the field by a number of engineers has confirmed this In trials at the Institute of Cryogenics, University of Southampton using an automotive air-conditioning test rig, coefficients of performance of the order of 6% greater than R12 were obtained This and similar test work has shown that the efficiency of Care 30 is better than R12 and hence , R134a The results of the test work undertaken at the University of Southampton are shown in figure 5

The results of tests by Bitzer comparing the performance of R290 and R22 are shown in figure 6

Care 50 has been formulated to give similar capacity to R22 and R502, and practical testing in both the laboratory and in the field by a number of engineers has confirmed this In trials by EA Technology using a calibrated refrigeration test rig the performance of Care 50 proved to be comparable to that of R22 The results are shown in figure 7

Charge quantity.

Hydrocarbon refrigerants have lower densities (but higher latent heats per unit weight and better thermal conductivities) than CFCs, HCFCs and HFCs. In practice this means that the charge required in weight terms is lower than that for halocarbons to give the same volumetric flow rate and the same capacity

In general the charge for hydrocarbon refrigerants is approximately 40% that for CFC, HCFC or HFC refrigerants by weight (This often results in cost savings) **The volume of refrigerant needed is the same.**

Compatibility of hydrocarbons with refrigeration system materials.

Hydrocarbon refrigerants are compatible with the vast majority of materials that would be used with traditional refrigerants, including

- metal components,
- mineral, alkyl benzene and ester oils,
- compressor motor materials,
- most seal materials

Hydrocarbons are not compatible with natural rubber or silicone. It is unlikely that such materials are used in systems, but they may be used in compressor shaft seals, other seals and gaskets, solenoid valves, hoses and charging and recovery equipment. **If you are in any doubt, you are advised to contact the equipment manufacturer or supplier.**

Care 30 and Care 50 are designed to be suitable for use in existing systems (although they can also be used in new systems). The materials compatibility ensures they can be used with minimum system modifications and by following a simple drop-in procedure.

Use of hydrocarbon refrigerants: flammability.

Hydrocarbon refrigerants are flammable in the following concentrations in air

Flammability limit	**R600a**	**Care 30**	**R290**	**Care 50**
Lower (LFL) vol %	1.85	1.95	2.0	2.2
Upper (UFL) vol %	8.5	9.1	10.0	10.2

An ignition source at a temperature of more than 460°C is also needed for combustion to occur. Potential ignition sources include

- naked flames
- anything at a temperature above 460°C
- sparks from electrical components

In general, Calor Gas Refrigeration recommends that the charge level in any system is related to the volume of the space into which the refrigerant could leak. The recommended charges in the following table have been calculated from the lower explosive limit of the refrigerant (approximately 2% in air by volume) If the refrigerant is evenly dispersed in the room then the amount of refrigerant must be below the figure in the third column to prevent potential combustion The suggested maximum charge in the fourth column is between one fifth and one sixth of this to provide a high safety margin and to allow for the fact that the refrigerant may not be evenly dispersed

Room size	**Room volume, m^3**	**Weight of hydrocarbon to reach LFL***	**Suggested maximum charge**
2m x 2m x 2m	8	340 grams	70 grams
3m x 3m x 3m	27	1 1 kg	200 grams
4m x 4m x 4m	64	2 7 kg	500 grams
5m x 5m x 5m	125	5 2 kg	1 kg

* LEL = lower flammability limit

Electrics on the refrigeration system should be sealed or be of the non-sparking type, e g. solid state. If any part of the refrigeration system is below ground the charge should be limited to 1 kg because the refrigerant is heavier than air and in the event of a leak would not be dispersed

In general the following guidelines should be followed

- limit the charge quantity to the suggested maximum charge if the system is indoors with no additional safety measures,

or

- eliminate ignition sources by using only sealed or non-sparking electrical components (general experience with hydrocarbons shows there are unlikely to be problems with conventional refrigeration components) and by eliminating naked flames,

or

- use permanent atmosphere monitoring equipment designed to give an alarm if the refrigerant concentration in the air approaches the lower flammability limit

Many countries are revising refrigeration safety standards to allow the safe application of hydrocarbon refrigerants In general the amount of charge that can be used is related to the information given in the above table The table below shows the recommended charge amounts given in the new British Standard 4434: 1995 (Safety and environmental aspects in the design, construction and installation of refrigerating appliances and systems)

Occupancy category	**Maximum hydrocarbon refrigerant charge weight**
A public areas, large number of people, people sleeping etc	1 5 kg in sealed systems. 5 kg in indirect systems in special machinery rooms
B commercial premises, offices etc	2 5 kg in sealed systems 10 kg in indirect systems in special machinery rooms
C very few people - factories etc authorised access only	10 kg in humanly occupied areas. 25 kg in special machinery rooms Unlimited in the open air or all refrigerant containing parts are in a special machinery room.

Refrigerant containment is traditionally very poor in commercial systems Whatever refrigerant is being used, containment can and should be improved (in the case of R12 and R134a to prevent expensive, environmentally damaging refrigerant escaping into the atmosphere, in the case of hydrocarbons to prevent leakage of flammable refrigerants) Containment can be improved by.

- using brazed joints instead of flares (brazed joints are more reliable and less prone to failure),
- using suitable flexible hose in place of copper tube for pressure switch connections (such connections are very prone to leakage, especially on the high pressure side),
- ensuring vibration transmission from the compressor is as low as possible by flexibly mounting the compressor and by using flexible pipe work connections where appropriate,
- using good quality valves and always fitting valve caps,
- leak testing (and repair where necessary) as part of routine maintenance and as part of a CFC plant conversion

Component selection

R600a (Care 10) has different operating conditions and hence performance to traditional refrigerants Many hermetic compressor manufacturers now have data available for R600a

Care 30 is similar to R12 in operating conditions and performance, so R12 data can be used to select components, including pipe sizing, for Care 30 Care 30 is miscible with mineral, alkyl benzene and ester oils and does not require the use of an oil separator

R290 (Care 40) may require compressors that are slightly larger than those used for R22 (or R502) Some compressor manufacturers already provide selection information for R290 The performance comparison with R22 can be used to down rate R22 capacity data for the selection of components such as compressors

Care 50 is similar to R22 and R502 in operating conditions and performance, so R22 or R502 data can be used to select components for Care 50 Care 50 is miscible with mineral, alkyl benzene and ester oils and should not require the use of an oil separator

Use of Care 30 and Care 50 in existing systems.

Refrigeration systems using CFCs (or HCFCs) can be converted to use alternative, less environmentally damaging refrigerants by using one of three procedures

- add in,
- drop in,
- retrofit

Many refrigerants could be used as "add ins", that is they are used to top up a system without removing the remaining CFC HCFC first This is **not** a recommended procedure because it renders the charge un-reclaimable Although the charge can be recovered and cleaned, the refrigerants cannot be separated easily and therefore each cannot be re-used

The term "drop-in" can be a misnomer because although the refrigerant itself requires no modifications to the system, some work should be done as good refrigeration practice because the system may be opened to the atmosphere This normally includes replacing the filter-drier

Care 30 is a "drop-in" replacement for R12 Care 50 is a "drop-in" replacement for R22 and R502 They can operate with the existing oil, whether it is a mineral, alkyl benzene or an ester type Some modifications may be needed to system electrics to eliminate potential sources of ignition such as sparking electrical components

The retrofit procedure is used where the alternative refrigerant cannot operate with the existing mineral oil. It is a lengthy, costly procedure which must be planned in advance in order to make the necessary number of oil changes to reduce the remaining mineral oil proportion to an acceptable level

Figure 1, 2 use pressure / temperature graphs for Care 10, 30, 40, 50 / R12, 134a, 22, 502

Figure 3 Pressure temperature relationship for hydrocarbon refrigerants.

Pressure, bar gauge	R600a, °C	Care 30 Bubble temperature, °C	Care 30 Dew temperature, °C	R290, °C	Care 50 Bubble temperature, °C	Care 50 Dew temperature, °C
-0.7	-39.4					
-0.6	-33.4					
-0.5	-28.6					
-0.4	-24.5					
-0.3	-20.9	-40.2	-31.4	-50.1	-57.3	-51.1
-0.2	-17.7	-37.2	-28.4	-47.3	-54.4	-48.3
-0.1	-14.8	-34.4	-25.6	-44.7	-51.7	-45.8
0	-12.1	-31.9	-23.2	-42.4	-49.3	-46.5
0.5	-1.2	-21.6	-13.0	-32.8	-39.6	-34.0
1.0	7.1	-13.7	-5.2	-25.4	-32.1	-26.7
1.5	14.0	-7.1	1.2	-19.4	-25.9	-20.7
2.0	19.9	-1.5	6.7	-14.2	-20.6	-15.6
2.5	25.0	3.4	11.5	-9.6	-16.0	-11.1
3.0	29.7	7.8	15.8	-5.5	-11.8	-7.0
3.5	33.9	11.9	19.8	-1.8	-8.1	-3.4
4.0	37.8	15.6	23.4	1.7	-4.6	0
4.5	41.4	19.0	26.8	4.9	-1.4	3.1
5.0	44.8	22.3	29.9	7.9	1.7	6.1
5.5	48.0	25.3	32.9	10.7	4.5	8.8
6.0	51.0	28.2	35.6	13.3	7.2	11.4
6.5	53.8	30.9	38.3	15.8	9.7	13.9
7.0	56.5	33.5	40.8	18.2	12.1	16.2
7.5	59.1	36.0	43.2	20.5	14.4	18.5
8.0	61.5	38.4	45.5	22.7	16.6	20.6
8.5	63.9	40.6	47.7	24.8	18.7	22.7
9.0	66.2	42.8	49.8	26.8	20.8	24.6

10.0	70.5	47.0	53.8	30.7	24.6	28.4
11.0	74.6	50.9	57.5	34.3	28.3	31.9
12.0		54.6	61.1	37.6	31.7	35.2
13.0		58.0	64.4	40.8	34.9	38.3
14.0		61.4	67.6	43.9	37:9	41.3
15.0		64.5	70.6	46.8	40.8	44.1
16.0				49.5	43.6	46.8
17.0				52.2	46.3	49.3
18.0				54.8	48.8	51.8
19.0				57.2	51.3	54.2
20.0				59.6	53.7	56.5
21.0				61.9	56.0	58.7
22.0				64.1	58.2	60.8
23.0				66.2	30.4	62.9
24.0				68.3	62.5	64.9

Figure 4, R600a vs R12 compressor size

Figure 5, Use latest data from Southampton University showing efficiency comparison with R12.

Figure 6, Use Bitzer data for R290 / R22 comparison (acknowledge Bitzer).

Figure 7, Use EA Technology information

Figure 8, 9, 10, 11 pressure enthalpy charts for R600a, Care 30, R290, Care 50

Handling of Hydrocarbon Refrigerants

In many respects hydrocarbon refrigerants are very similar to traditional refrigerants. This section outlines:

- general safety considerations;
- charging,
- leak detection

General safety considerations.

Chemical safety data sheets for the Care hydrocarbon refrigerant range are available from Calor Gas Refrigeration The main points regarding safety in which they differ from CFC and HCFC refrigerants are highlighted as follows

- they are classified as a **flammable gases** and are flammable in concentrations in air of between approximately 2% and 10% by volume;
- small fires should be tackled with dry powder extinguishers, otherwise vacate the area and call the fire service;
- accidental releases of **large** quantities of hydrocarbons can be dispersed with a water spray. The area should be evacuated (except for personnel dealing with the emergency) Sources of ignition should be isolated or extinguished If possible the refrigeration system should be isolated at the point of leak

There is no occupational exposure limit (OEL) for propane, iso-butane or ethane, and therefore for Care As a guide the OEL for liquefied petroleum gas is 1000 ppm This is the long term exposure limit for an eight hour working day, and is the same for R12 and other CFCs.

In other respects safety considerations are the same as for CFCs, HCFCs and HFCs

- contact with liquid refrigerant will cause a freeze burn (similar to frost bite), which should be treated by washing the area with cold or tepid water Medical attention may be necessary;
- gloves and goggles should be worn when handling refrigerant,
- hydrocarbon refrigerants are heavier than air and will therefore tend to collect in pits, trenches, basements, well type display cases / chest freezers Such areas should be ventilated to disperse vapour,

- they will displace air and are thus asphyxiants in high concentrations. At lower concentrations lack of oxygen will cause dizziness, nausea, increased depth and frequency of breathing and ultimately unconsciousness. If affected a person should be removed to an uncontaminated area, kept warm and at rest. Artificial respiration should be given if breathing has stopped or shows signs of failing Medical attention should be sought

Handling of cylinders.

Guidelines for safe cylinder handling differ very little from other refrigerant cylinders and are as follows:

- do not remove or obscure official labelling on a cylinder;
- always fit the valve cap when the cylinder is not in use;
- store and use cylinders in dry, well ventilated areas remote from fire risk;
- do not expose cylinders to direct sources of heat such as steam or electric radiators;
- do not repair or modify cylinders or cylinder valves;
- always use a proper trolley for moving larger cylinders, even for a short distance - never roll cylinders along the ground;
- only use approved cylinder accessories,
- take precautions to avoid oil, water or foreign matter entering the cylinder,
- if it is necessary to warm the cylinder use only water or air, not naked flames or radiant heaters;
- always weigh the cylinder to check if it is empty - its pressure is not an accurate indication of the amount of refrigerant remaining in the cylinder;
- do not refill the cylinders.

Cylinders should be stored and transported according to local regulation for hydrocarbons (liquefied petroleum gas).

Charging hydrocarbon refrigerants.

This section outlines correct charging procedure for hydrocarbon refrigerants

In common with all refrigerant blends Care 30 and Care 50 should be charged in the liquid phase to maintain the correct composition of the blend It is important when charging a liquid into the system to take great care to ensure liquid refrigerant does not return to the compressor This will damage the compressor and may result in complete failure

R600a and R290 are single substances and can be charged as liquid or gas

Before a system is ready to be charged with any refrigerant it should be tested for safety and leak tightness, and then evacuated to remove all gases and moisture

General charging guidelines

These points are general guidelines to follow when charging hydrocarbon refrigerants

- always charge Care 30 and Care 50 in the liquid phase to retain the blend composition in both the system and the cylinder,
- always use the cylinder in the upright position,
- use hoses which are as short as possible to minimise the amount of refrigerant contained in them,
- if a large system is to be charged the charging equipment, hoses and system must be earthed to prevent a build up of static electricity In smaller systems (i e domestic appliances, small commercial systems and transport refrigeration and air conditioning applications) the flow of refrigerant will be insufficient to generate static,
- always remove air from lines preferably by evacuating the lines with a vacuum pump If this is not possible the lines can be purged, with low pressure gas if possible, or very carefully with liquid, allowing as little refrigerant as possible to escape,
- avoid naked flames when charging, for example there should be no smoking Display "No Smoking" signs,
- have a dry powder fire extinguisher adjacent to the charging area,
- label the system when charging is complete The label should be prominently positioned and should state which refrigerant has been charged into the system and that it is flammable Such labels are supplied with the refrigerant

Charging using a charging still

When a charging still is used for Care 30 or Care 50 liquid refrigerant should be charged into the still, and liquid taken out Great care should be taken if the only charging connection is into the suction line of the refrigeration system. It is possible to fit an expansion device into the line between the charging still and the suction line This could be a simple capillary tube which will evaporate the liquid before it enters the system

If R600a or R290 is being used, gas can be taken out of the still

Most charging stills measure the refrigerant by volume The volume of hydrocarbon required will be the same as that of the halocarbon refrigerant it is replacing For example when charging Care 30 into an R12 system, fill the charging still to the amount specified for R12 and use this amount in the system **Although the still is calibrated in weight it is actually measuring a volume.**

Charging without a charging still

When a charging still is not used, liquid can be charged into the liquid line in the normal way If it is required to charge Care 30 or Care 50 into the suction line (for example to top up a system or to complete the initial charging of a system) then an expansion device (for example a capillary tube) can be used to evaporate the refrigerant before it enters the system Alternatively the liquid can be throttled through a manifold set

If refrigerant is weighed into the system the charge of hydrocarbon will be approximately 40% that of the halocarbon refrigerant it replaces

The system can be charged until the liquid line sight glass clears However, it should be remembered that bubbles in the sight glass do not always mean the system is undercharged. They can also indicate a blockage in the liquid line filter drier or that the condenser is seriously undersized

Beware of overcharging

Because of the smaller weights likely to be involved with hydrocarbon refrigerant charges it is more likely that systems are overcharged because there is less margin for error Great care should therefore be taken to accurately charge a small system. For example, there may be more refrigerant in the charging hose than is needed in a domestic appliance

Leak detection of hydrocarbon refrigerants.

A halide torch (or any other detector using a naked flame) **must not** be used to detect hydrocarbon refrigerants

Electronic leak detectors will usually detect hydrocarbons, but the sensitivity may not be great enough, or may need adjusting. The leak detector should be electrically intrinsically safe

Leak detection fluids are suitable for use with hydrocarbons The use of detergents with chlorine in should be avoided as the chlorine may react with hydrocarbons and corrode copper pipe work.

Oil additives, such as the Spectroline fluorescent leak detection system, will work with hydrocarbons

If a leak is found don't assume it is the only one - check the whole system

If a leak is suspected from a hydrocarbon refrigerant plant all naked flames should be removed / extinguished

Leakage from plant which has been converted from CFCs / HCFCs

Alternative refrigerants, when used to convert CFC or HCFC plant, may sometimes leak where the old refrigerant did not This is usually due to the different reaction with some seal materials, and also possibly due to smaller refrigerant molecule size Such leakage may also occur with hydrocarbon refrigerants (although it is less likely), so systems should be leak tested after the refrigerant has been charged in

Repairing leaks

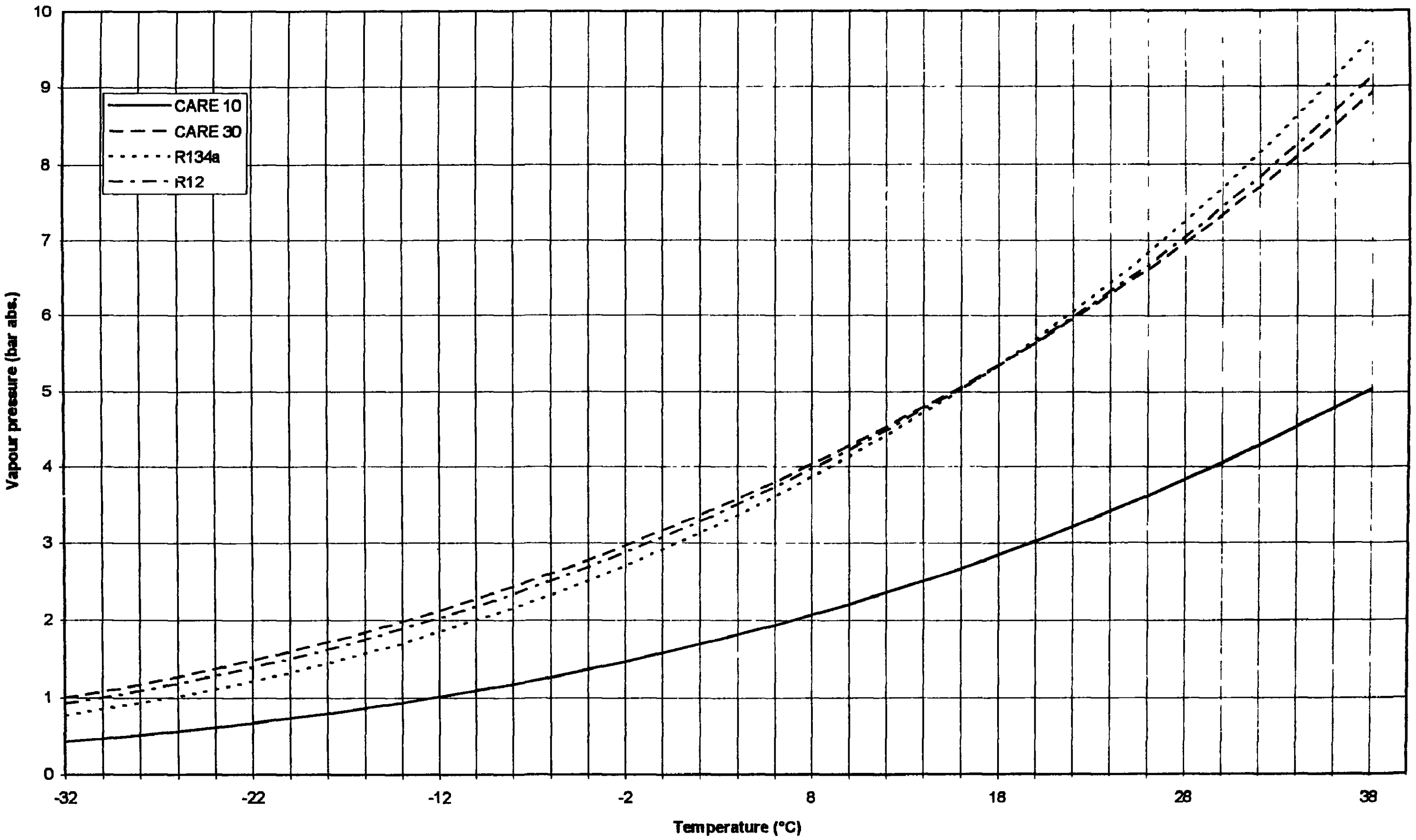
If a leak is found which requires brazing, all the refrigerant should be recovered from the plant or isolated in a part of the system remote from the leak Dry nitrogen should be purged through the lines being brazed to prevent oxides forming inside the pipes - a reaction which will cause subsequent damage to the compressor This is good practice with all refrigerants, but elimination of the refrigerant is particularly important with hydrocarbons

Disposal of hydrocarbon refrigerants

Care should be taken when servicing or scrapping a system The venting of hydrocarbon refrigerant will result in a potentially combustible mixture being present in the air around the system In addition, potentially damaging oil will also escape from the system

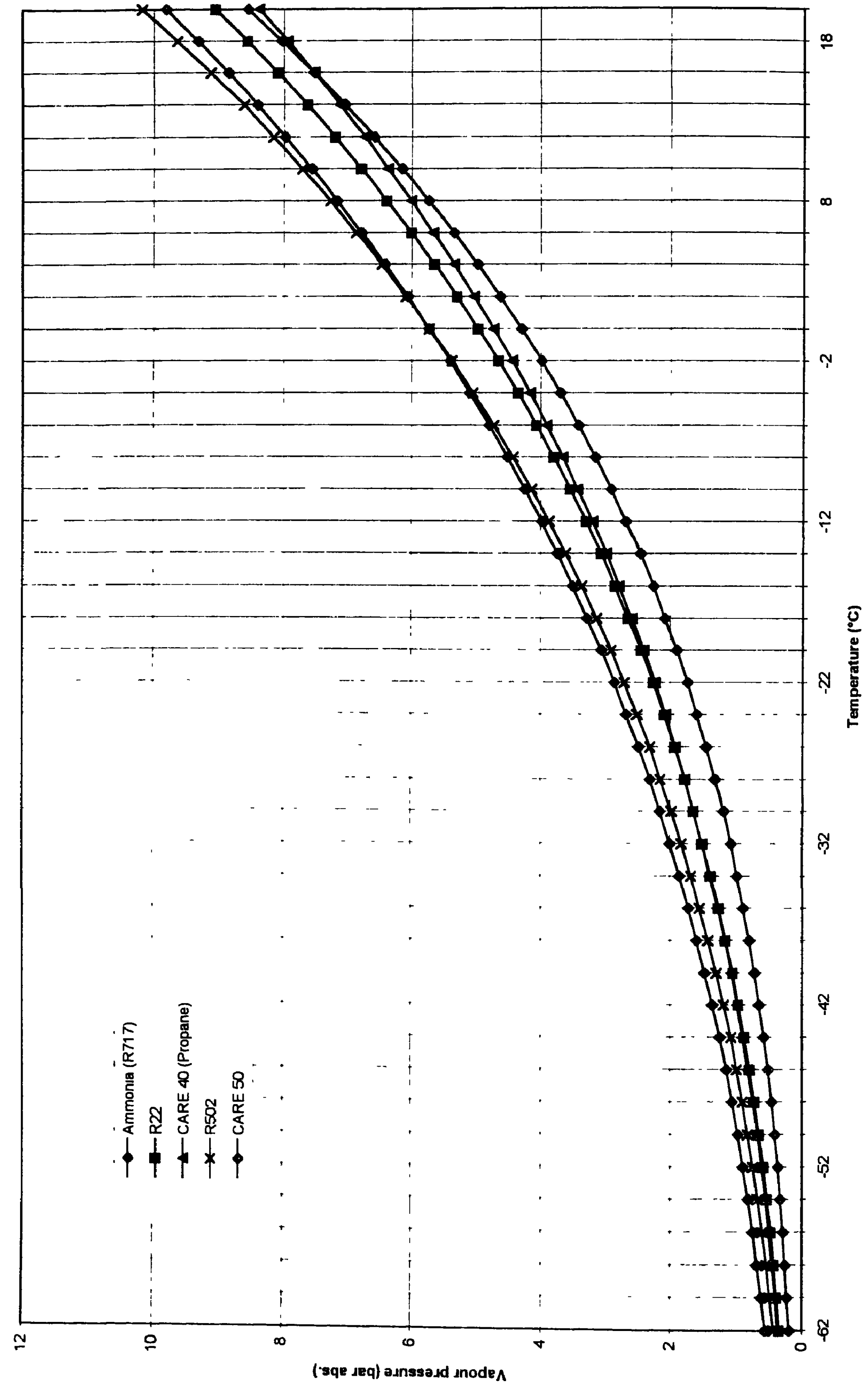
It is dangerous to burn the hydrocarbon refrigerant as it is vented - this will result in uncontrolled combustion and possible toxic products from oil decomposition

Figure 1 Pressure / temperature graph for CARE 10 & CARE 30 against R12 & R134a



Comparison in vapour pressure vs. temperature profile for R12, R134a, CARE 10 CARE 30

Figure 2 Pressure/temperature graph for CARE 40 & CARE 50 against R22, R502 & Ammonia



Comparison between CARE 40, CARE 50, R22, R502 Ammonia

Figure 4

Comparison of compressor swept volume requirements for CARE 10 vs. R12 at identical operating conditions

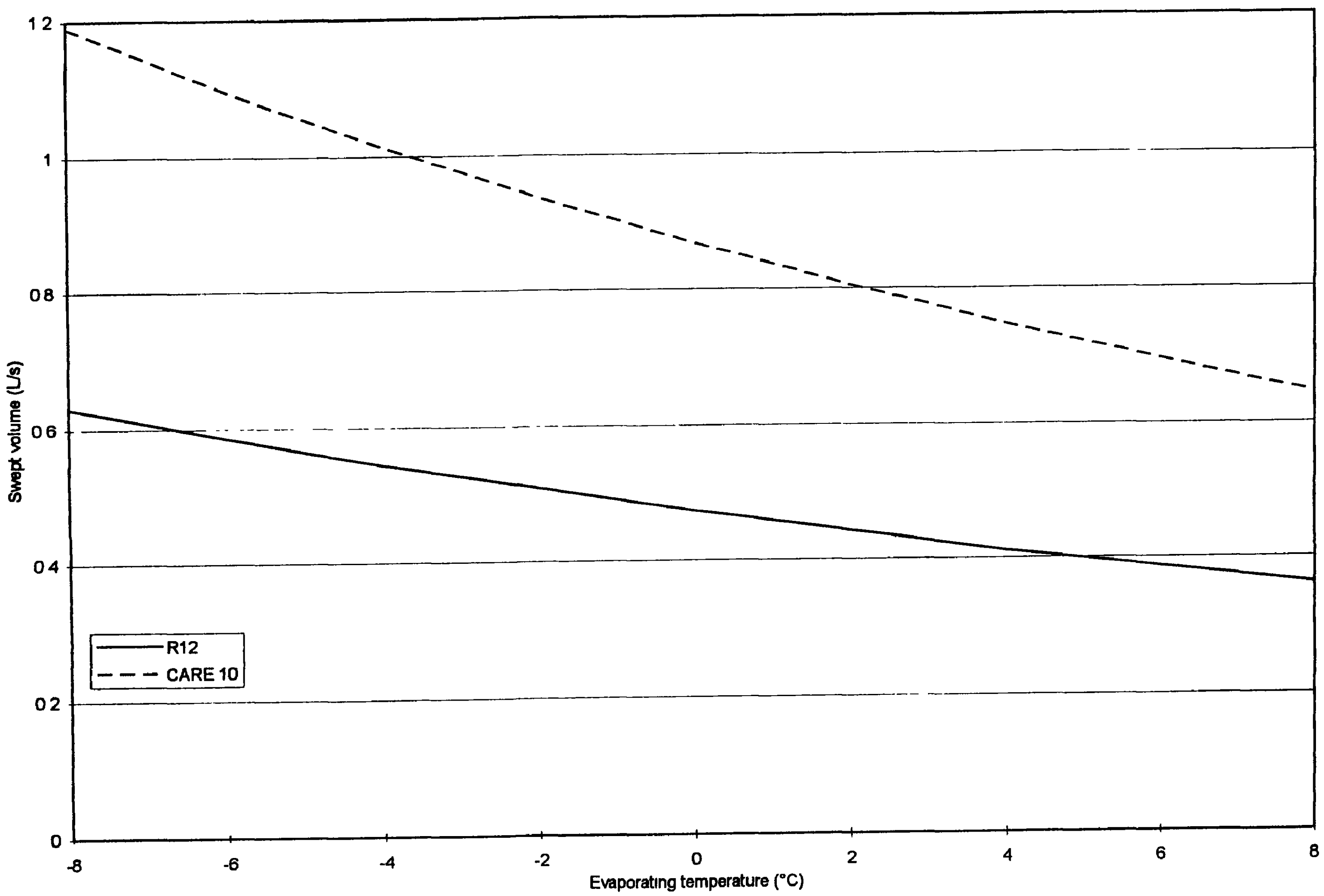


Figure 5 Data from Southampton University showing efficiency comparison of CARE 30 with R12

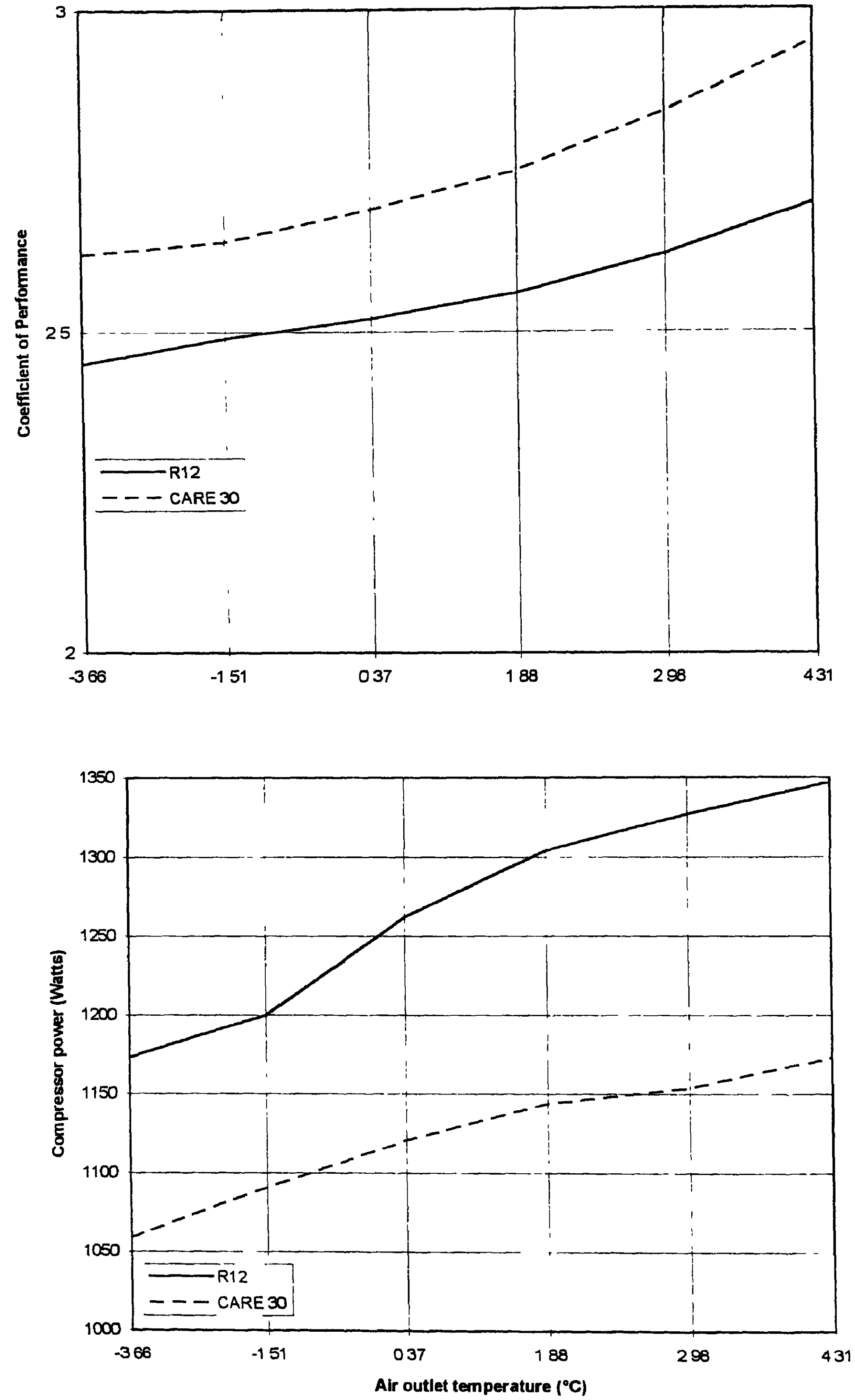


Figure 6 Data from Bitzer showing compressor performance of CARE 40 against R22

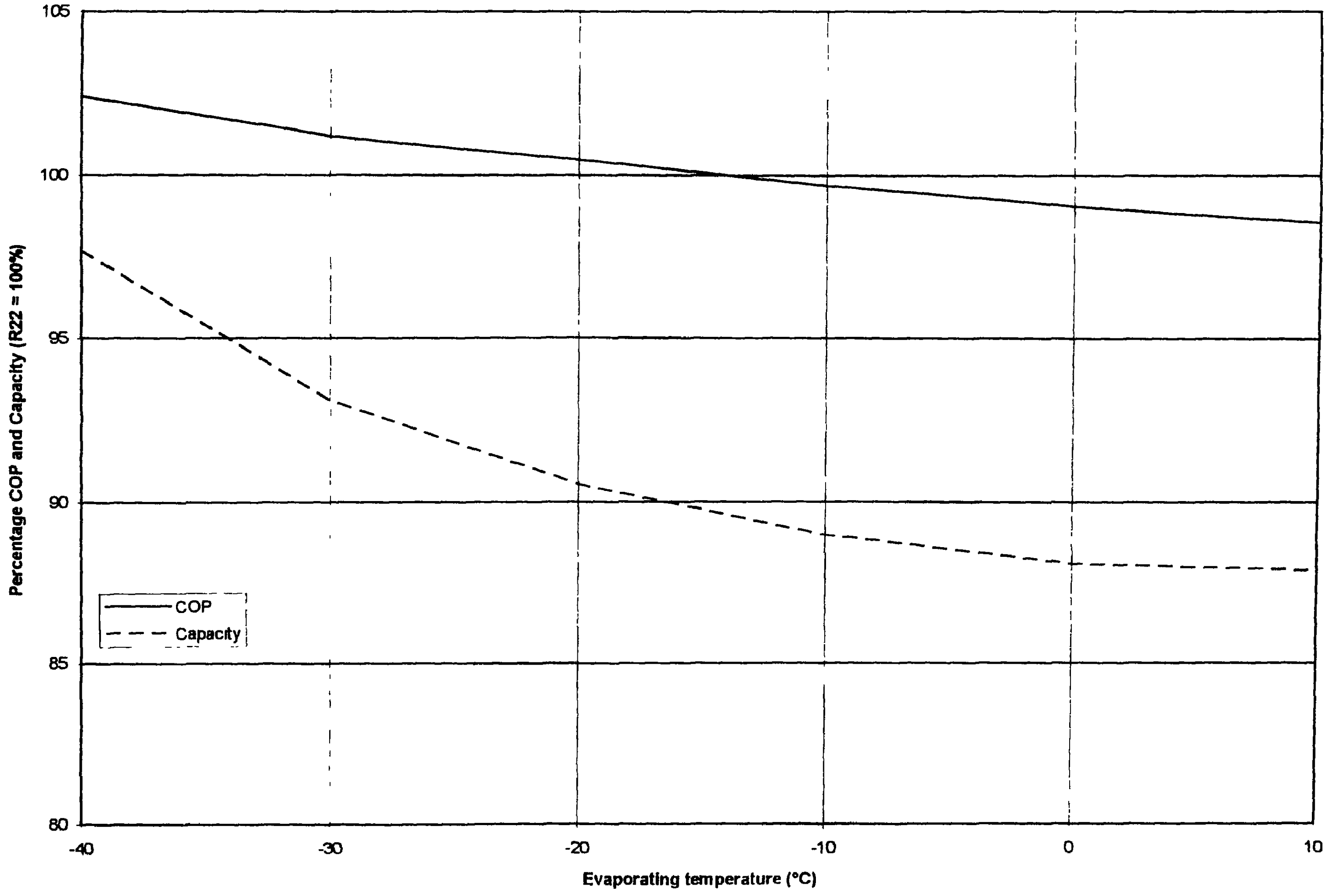
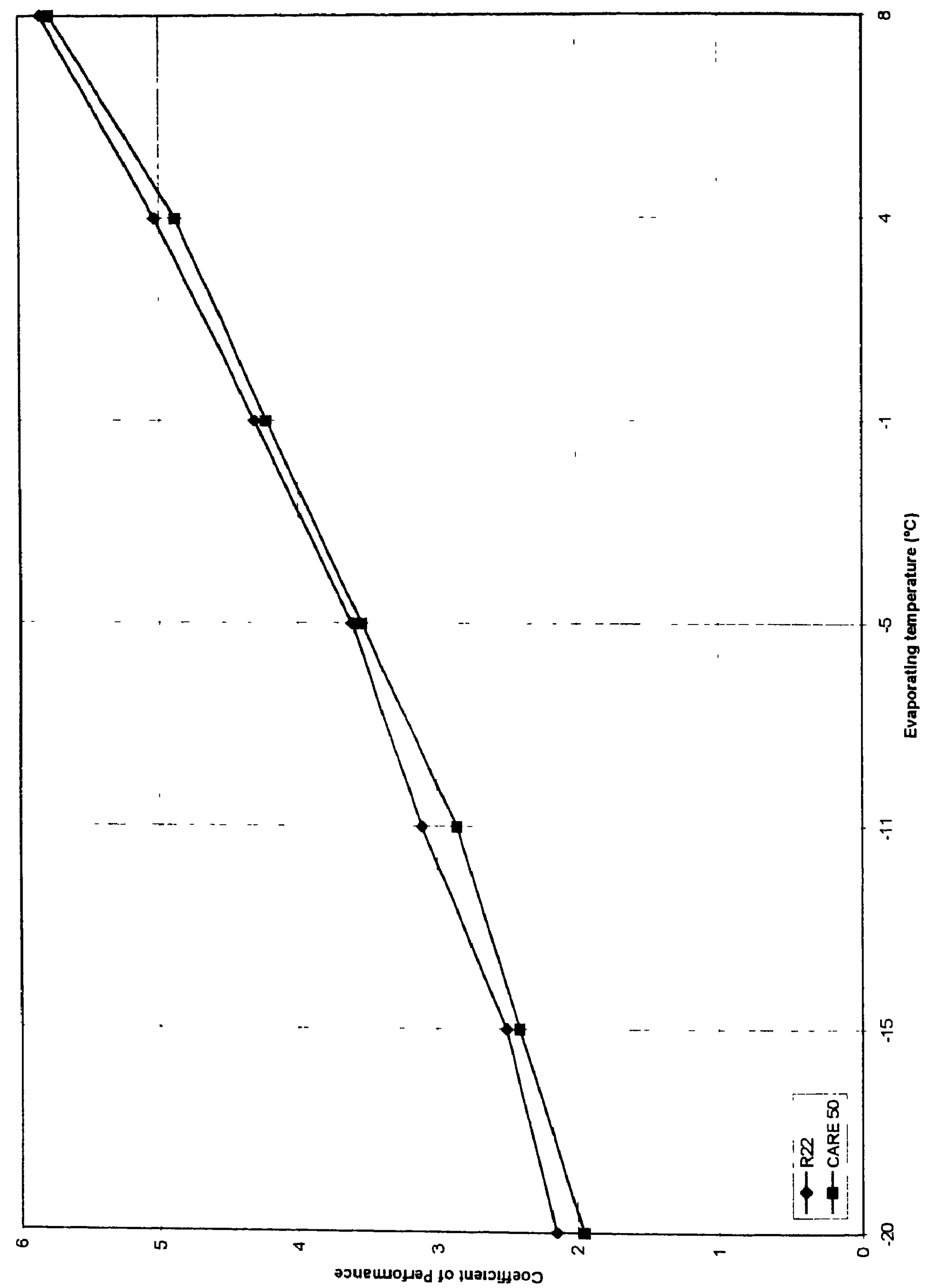


Figure 7 Data from EA Technology showing efficiency comparison of CARE 50 and R22



CARE REFRIGERANTS

PRESSURE ENTHALPY

- **CARE 10** figure 8
- **CARE 30** fig 9
- **CARE 40** fig 10
- **CARE 50** fig 11.

Calor Gas Refrigeration
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Slough
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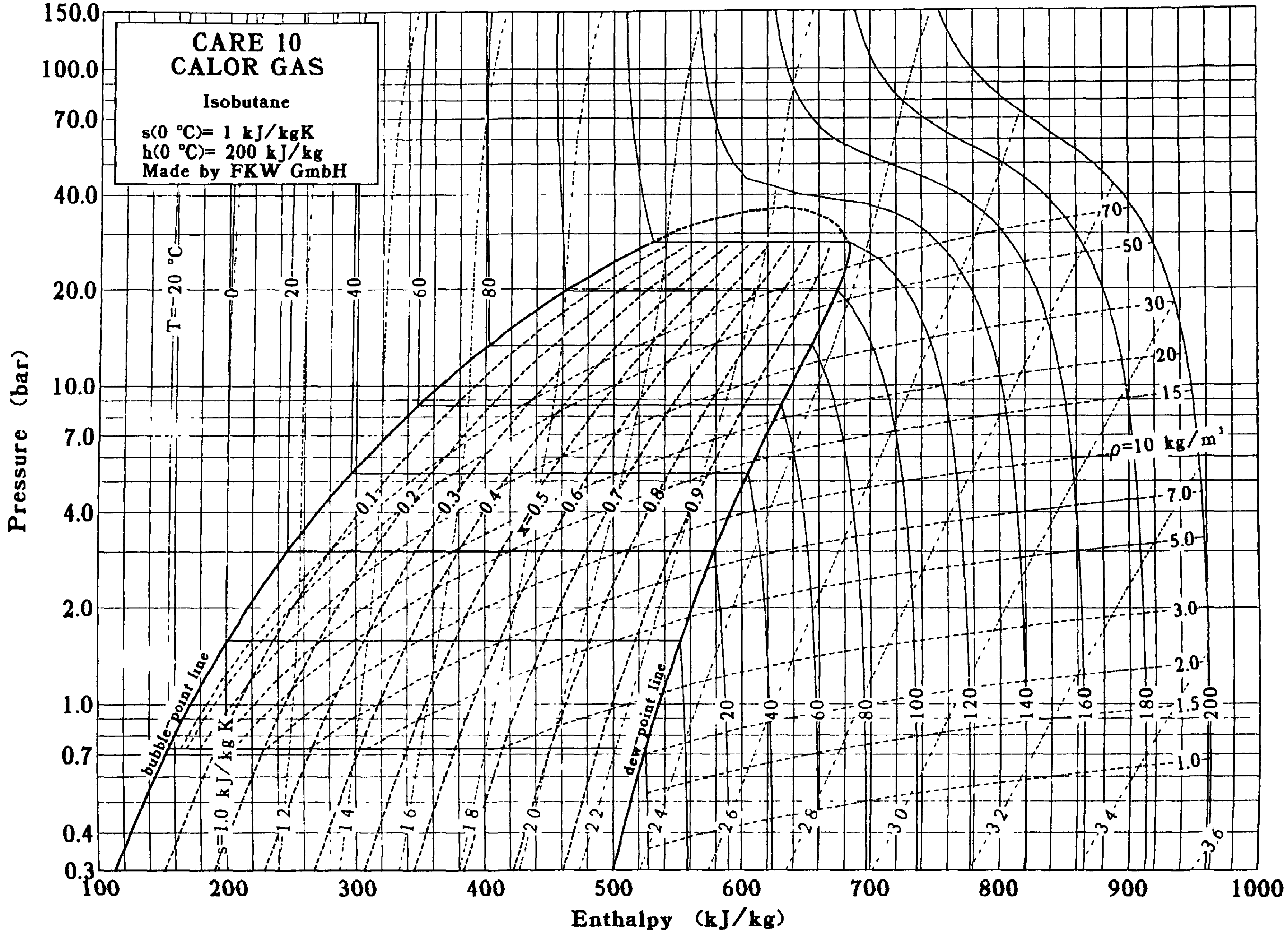
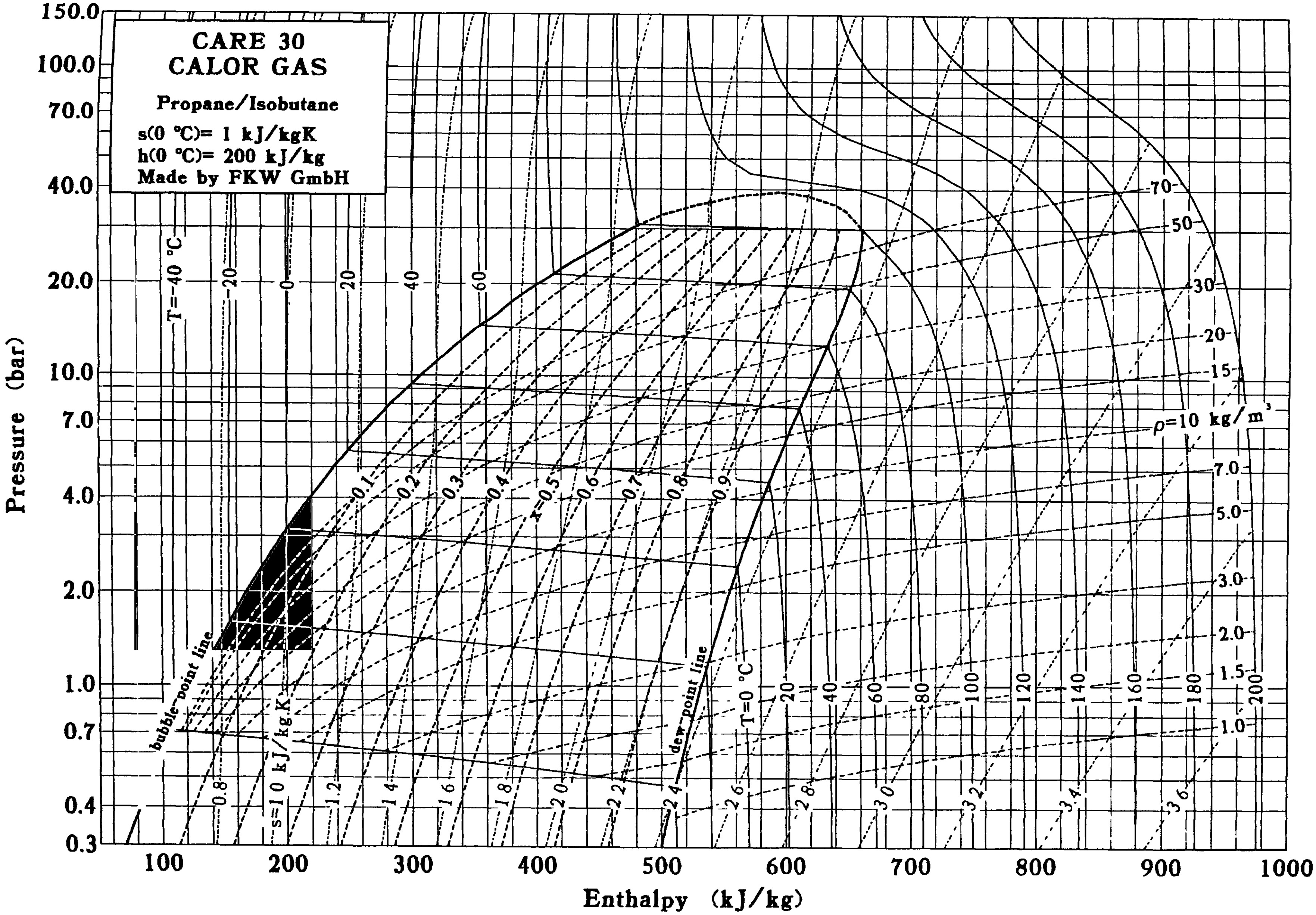
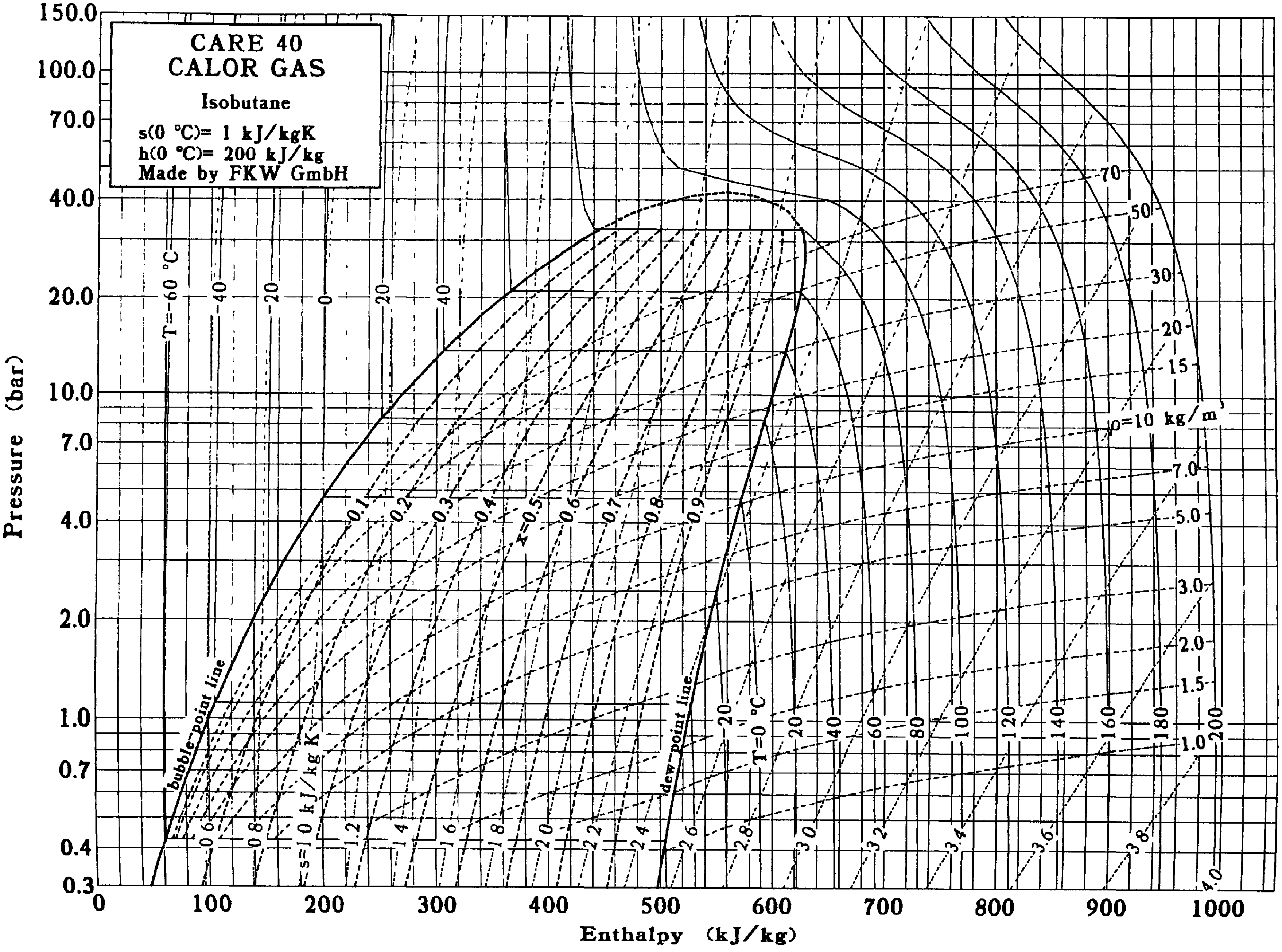
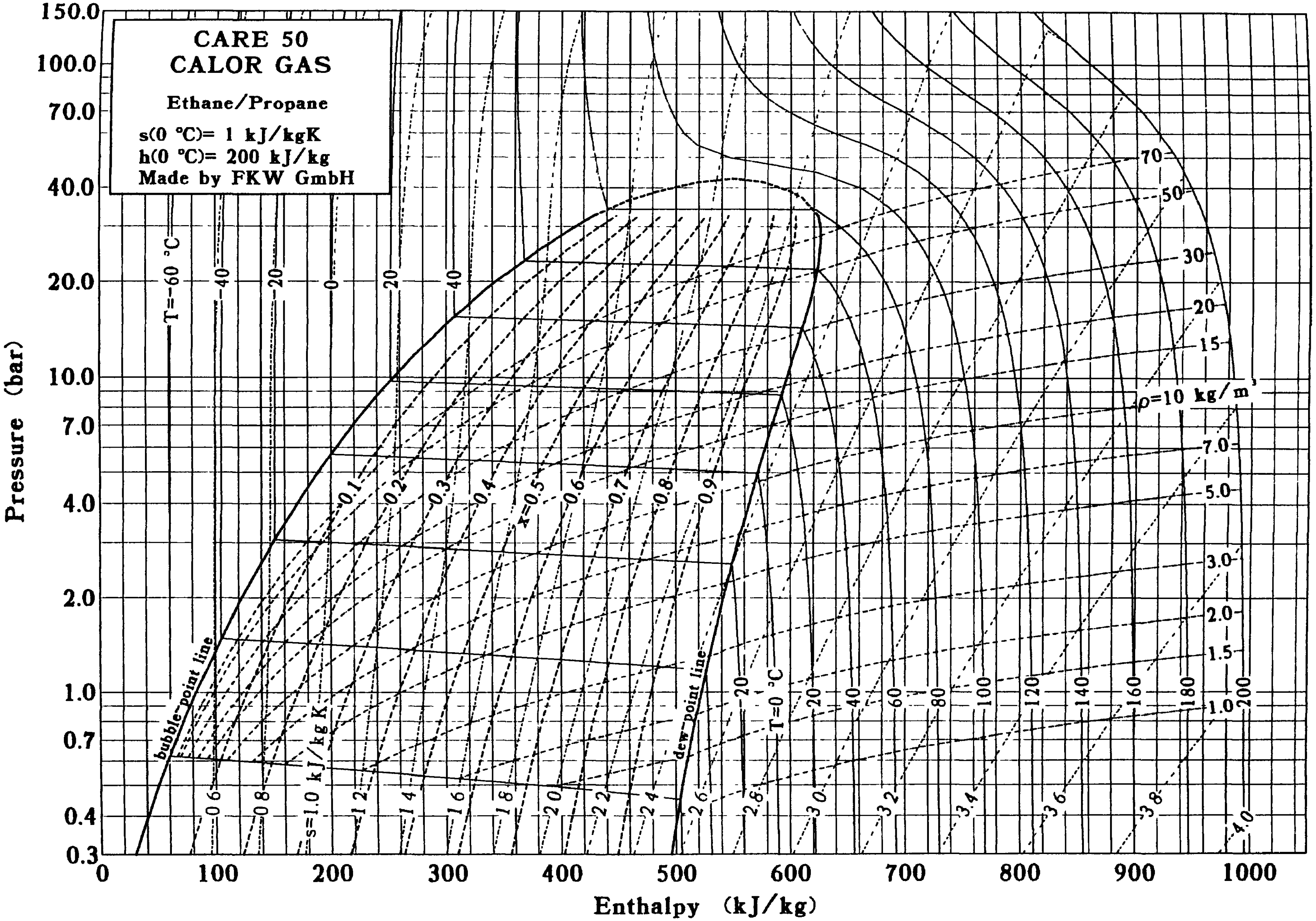

CARE 10
CALOR GAS
Isobutane
s(0 °C)= 1 kJ/kgK
h(0 °C)= 200 kJ/kg
Made by FKW GmbH
Pressure (bar)
150.0
100.0
70.0
40.0
20.0
10.0
7.0
4.0
2.0
1.0
0.7
0.4
0.3
Enthalpy (kJ/kg)
100
200
300
400
500
600
700
800
900
1000
T=-20 °C
0
20
40
60
80
100
120
140
160
180
200
x=0.5
0.1
0.2
0.3
0.4
0.6
0.7
0.8
0.9
ρ=10 kg/m³
70
50
30
20
15
7.0
5.0
3.0
2.0
1.5
1.0
s=1.0 kJ/kg K
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
bubble-point line
dew point line


CARE 30
CALOR GAS
Propane/Isobutane
s(0 °C)= 1 kJ/kgK
h(0 °C)= 200 kJ/kg
Made by FKW GmbH
Pressure (bar)
150.0
100.0
70.0
40.0
20.0
10.0
7.0
4.0
2.0
1.0
0.7
0.4
0.3
Enthalpy (kJ/kg)
100
200
300
400
500
600
700
800
900
1000
T=-40 °C
-20
0
20
40
60
T=0 °C
20
40
60
80
100
120
140
160
180
200
x=0.5
0.1
0.2
0.3
0.4
0.6
0.7
0.8
0.9
bubble-point line
dew-point line
s=1 0 kJ/kg.K
0.8
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
ρ=10 kg/m³
70
50
30
20
15
7.0
5.0
3.0
2.0
1.5
1.0


CARE 40
CALOR GAS
Isobutane
s(0 °C)= 1 kJ/kgK
h(0 °C)= 200 kJ/kg
Made by FKW GmbH
Pressure (bar)
150.0
100.0
70.0
40.0
20.0
10.0
7.0
4.0
2.0
1.0
0.7
0.4
0.3
Enthalpy (kJ/kg)
0
100
200
300
400
500
600
700
800
900
1000
T=-60 °C
-40
-20
0
20
40
-20
T=0 °C
20
40
60
80
100
120
140
160
180
200
bubble-point line
dew-point line
0.1
0.2
0.3
0.4
x=0.5
0.6
0.7
0.8
0.9
ρ=10 kg/m
70
50
30
20
15
7.0
5.0
3.0
2.0
1.5
1.0
0.6
0.8
s=1.0 kJ/kg K
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0


CARE 50
CALOR GAS
Ethane/Propane
s(0 °C)= 1 kJ/kgK
h(0 °C)= 200 kJ/kg
Made by FKW GmbH
Pressure (bar)
150.0
100.0
70.0
40.0
20.0
10.0
7.0
4.0
2.0
1.0
0.7
0.4
0.3
Enthalpy (kJ/kg)
0
100
200
300
400
500
600
700
800
900
1000
T=-60 °C
-40
-20
0
20
40
bubble-point line
dew point line
x=0.5
0.1
0.2
0.3
0.4
0.6
0.7
0.8
0.9
T=0 °C
-20
20
40
60
80
100
120
140
160
180
200
ρ=10 kg/m³
70
50
30
20
15
7.0
5.0
3.0
2.0
1.5
1.0
s=1.0 kJ/kg K
0.6
0.8
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0

PROPERTIES OF CYCLOPENTANE BLOWN FOAM

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CONFERENCE ON HYDROCARBON FLUIDS IN DOMESTIC
AND COMMERCIAL REFRIGERATION APPLIANCES

ECO-REFRIGERATION CONFERENCE - DELHI - FEBRUARY 13/14TH 1996

PROPERTIES OF CYCLOPENTANE-BLOWN FOAM

Dr. Mike Jeffs - ICI Polyurethanes

1 INTRODUCTION

Polyurethane rigid foam has achieved an almost 100% share of the market for insulation materials in household refrigerators and freezers since its introduction in Europe in the late 1950s to replace other insulants, mostly fibreglass This has been achieved because of the very significant advantages which it offers in the manufacturing process and end product properties

The composition of the foam has changed during this period MDI is now the dominant isocyanate and many types of polyols have and are being used However, for more than thirty years the universal blowing agent was CFC 11 It gave unrivalled insulation properties and had no apparent negative features until its role, with other CFCs, in ozone depletion was realised and its phaseout proscribed by the Montreal Protocol and other, national, controls

There has been a five year period of uncertainty during which many replacement blowing agent options have been evaluated Several HCFCs have been extensively evaluated and some, notably HCFC 141b, are in use However, cyclopentane was introduced in German refrigerator factories in 1993 and has since become the dominant blowing agent in Europe and its use in spreading rapidly to both developed and developing countries worldwide This acceptance is based on its environmental properties of zero ODP and very low GWP which offer the manufacturers of appliances a period of stability The technology offers a one step change to a durable solution and where developing country enterprises can learn from the experience of those in developed countries

This paper describes the properties of cyclopentane-based foams in comparison with CFC 11 and with the other options It also indicates that precautions must be taken because of the flammability of cyclopentane These precautions are described in detail in an accompanying paper (reference 1)

It will also be made clear that the technology is still evolving and there will be improvements in the properties of cyclopentane-based foams and refinements in the composition of the blowing agent itself The application of vacuum panels and the potential use of liquid HFCs will also be discussed

2. TECHNICAL REQUIREMENTS OF POLYURETHANE RIGID FOAMS AND BLOWING AGENTS

Modern refrigerators and freezer designs rely heavily on the properties of the insulating foam which is, in turn, dependent on the characteristics of the blowing agent.

The prime requirement is to provide **long term insulation** to reduce the energy consumption of the appliance whilst maintaining the contents at the required temperature and to prevent moisture condensing on its outside surfaces The foam also provides **strength** and **dimensional stability** to the structure allowing the use of thinner guage steel and plastic (liners) with considerable cost and weight savings These properties must be **long lasting** so that the appliance has a useful life of 20 years or more

The processing properties of the foam are critical in the cabinet manufacturing stage The reacting foam has to flow throughout the cabinet in a minimum time so that product quality and production rates are maintained

This short statement indicates the critical technical aspects for the evaluation of any new foam technology such as one based on a different blowing agent These are complementary to requirements of safe operation in the factory and meeting contemporary environmental standards

3 BLOWING AGENT OPTIONS

This section covers the blowing agent options which have been considered during the CFC replacement programme by appliance manufacturers and their suppliers. The principal characteristics of these are shown in Table 1

Table 1 - Blowing Agents - Characteristics

	CFC 11	HCFC 22 / HCFC 142b	HCFC 141b	HFC 134a	Cyclo-pentane
Chemical formula	$CFCl_3$	$CHClF_2/CH_3CClF_2$	CH_3CCl_2F	CH_2FCF_3	$(CH_2)_5$
Molecular weight	137	86/100	117	102	70
Boiling point (°C)	24	-41/-10	32	-27	50
Gas conductivity (mW/mK at 10°C)	7 4	9 9/8.4	8 8	12 4	11.0
Flammable limits in air (vol %)	None	None/ 6 7-14 9	7.3-16.0	None	1 4-8.0
TLV or OEL (ppm)	1000	1000/1000	500	1000	600
ODP	1 0	0 055/0.065	0 11	0	0
GWP (100 yr ITH)	3400	1700/2000	630	1300	3

In traditional technologies CFC 11 has been used at concentrations of between 12 and 17% by weight of the polyurethane foam chemicals Technologies in Europe and those based on European technologies used concentrations in the range of 12-14% by weight In North America and Japan concentrations in the range 15-17% were the norm in order to optimise insulation values Most developing country technologies are of European origin, hence using CFC concentrations at the lower end of the range

The reduced CFC technology option is normally based on a CFC 11 concentration of 6-7% by weight The common definition of < 2.5 g/l equates to 7 to 7 5% by weight CFC 11 Reduced CFC technology is based on increasing the amount of CO_2 co-blowing by increasing water level in the formulation This gives increased CO_2 generation through the water-isocyanate reaction This technology has been a useful interim measure but is now outdated because of the availability of cyclopentane and other technologies

The mixed HCFC 22 / HCFC 142b option has been developed to counteract the comparatively rapid foam thermal conductivity ageing characteristics of HCFC 22, if used alone, and is normally used at a 40/60 molar ratio This ratio negates the flammable nature of HCFC 142b. This option is used by very few manufacturers and some in Europe which used it as an interim step have now fully converted to cyclopentane.

HCFC 141b has been a leading contender and is widely used in N. America Its comparatively high ODP of 0.11 has resulted in its replacement in other areas by cyclopentane. This is despite its good initial thermal conductivity

HFC 134a was used for a short time in Europe before being replaced by cyclopentane.

The use of CO_2 alone is not viable for domestic refrigerators and freezers because of a comparatively high initial foam thermal conductivity - which itself would require unit redesign - and, more importantly, the rapid ageing of the foam, even with the protection of plastic liners, to wholly unacceptable values

4. CYCLOPENTANE FOAM PROPERTIES

Since their introduction in 1993 polyurethane rigid foam systems designed for use with cyclopentane are now available from several suppliers although, arguably, the most highly developed are available from the main European suppliers who have been operating in that highly competitive market

Hydrocarbon foam technology is comparatively young and is still evolving The main development areas are

- Reduction of foam density - the first cyclopentane foams to be commercialised had to have a foam density up to 15% higher than had been used with CFC 11-based foams This has imposed a considerable cost penalty and has been due to the solubility of the cyclopentane in the foam matrix causing a loss of mechanical strength This had to be compensated by increasing the foam density to ensure freedom from foam shrinkage The development routes include optimisation of the foam strength through choice of polyol structure and the modification of the blowing agent to include n or iso-pentane in a blend or, more radically, replacement of cyclopentane by a n/iso pentane blend This latter solution has a negative effect on thermal conductivity, at least, at temperatures of 10°C or higher

- Reduction of thermal conductivity - Table 1 indicates that the vapour thermal conductivity of cyclopentane is higher than for CFC 11 In fact, all the alternatives are inferior to CFC 11 in this respect This effect is transposed through to the thermal conductivities of the respective foams Various routes exist to ameliorating this effect These include the optimisation of cell structures to obtain smaller cells and hence reduce the transfer of heat by radiation

The related phenomenon of the condensation of cyclopentane at low temperatures can affect the thermal conductivity of the foam at lower, for example, freezer operating temperatures. This, in turn, can be ameliorated by using blends with iso or n-pentane which can increase the vapour pressure in the cells.

A range of foam systems are available to meet the needs of manufacturers of domestic appliances Table 2 lists the formulation and the key parameters of three cyclopentane-based systems in comparison with "controls" based on CFC 11, reduced CFC 11 and HCFC 141b. Table 3 lists the foam properties of the same systems

Table 2 - Foam Systems - Formulation and Processing Parameters

Formulation No	Units	1	2	3	4	5	6
Blowing agent		CFC 11	Reduced CFC 11	HCFC 141b	Cyclo-pentane	Cyclo-pentane	Cyclo-pentane
Polyol	Pbw	100	100	100	100	100	100
Blowing agent	Pbw	26	15	18 7	11	12	13
Isocyanate	Pbw	126	140	154	135	161	138
Reaction times							
- cream	s	7	5	9	5	5	5
- string	s	53	45	65	43	45	40
- tack free	s	75	70	105	68	70	58
Free rise density	kg/m^3	20 6	22 0	22 4	25 0	25 0	22 6
Brett 200'20'5 cm							
- minimum fill	kg/m^3	29 6	31 0	34 2	35 0	35 5	33 5
- JDT 10% OP, 4 min	mm from 50	50 9	50 8	50 9	50 8	50.5	50 7

All the data displayed are for commercially used formulations The three cyclopentane-based systems are optimised for

- thermal conductivity - Formulation 4
- demould time - Formulation 5
- low density (and low viscosity) - Formulation 6

These effects are evident in the properties displayed in tables 2 and 3 Formulation 4 has a foam initial thermal conductivity only 3% above that of Formulation 2 (reduced CFC 11) which it is designed to replace. Formulation 5 shows, through the Brett mould data, curing or jig dwell time performance equal or superior to those of CFC 11-based formulations. Formulation 6 shows a step in the reduction of the foam density with a density increase of just under 10% relative to that of the reduced CFC 11 formulation compared to a density increase of 15% for Formulations 4 and 5

The HCFC 141b-based formulation shows the low foam initial thermal conductivity in keeping with its vapour phase conductivity being closest to that of CFC 11

Table 3 - Foam Systems - Typical Foam Properties

Formulation No	Units	1	2	3	4	5	6
Blowing agent		CFC 11	Reduced CFC 11	HCFC 141b	Cyclo-pentane	Cyclo-pentane	Cyclo-pentane
Average core density	kg/m^3	28 5	32 0	35 9	36 8	37 0	35 1
Thermal conductivity at 10°C	mW/mK	17 7	19 0	19 2	19 6	20 0	20 2
Compressive strength at 10%	kPa	150	149	180	234	241	185
Dimensional stability							
-25°C	% vol	< 1	< 1	< 1	< 1	< 1	< 1
+ 100°C	change	< 1	< 1	< 1	< 1	< 1	< 1
Closed cell content	%	95	94	95	96	96	95
Cell size	μm	250	238	180	170	182	180

The above properties were obtained with "pure" grade cyclopentane (> 95% cyclopentane) Experience has shown that the difference in overall performance with "technical" grade cyclopentane (about 70% cyclopentane) is very small The change in thermal conductivity is typically less than 0 5 mW/mK

5 AGEING PHENOMENA

Domestic refrigerators and freezers should have a service life of 20 years or more Unit failure caused by foam defects could arise from either loss of insulation value or shrinkage / dimensional instability These faults could take 10 or more years to manifest themselves - a far longer time scale than can be afforded when meeting an environmental challenge such as CFC 11 replacement

Rapid diffusion of the blowing agent can cause these failures Some alternatives, notably CO_2 plus HCFC 22, are known to diffuse rapidly out of the foam and also, possibly, through the ABS or PS inner liner For the other blowing agents it is not easy to differentiate Accelerated ageing studies (reference 2) of uncovered cyclopentane-based foams show that the ageing phenomenon is of the same time scale as CFC 11 and, although the initial thermal conductivity is typically up to one mW/mK higher than a reduced CFC 11 foam, this difference has disappeared after 4-5 weeks ageing at 70°C In turn CFC 11-based foams have been proven over many years of practical service

There is also discussion over the amount of ageing over the lifetime of a practical appliance in service One study (reference 3) indicated that the upward drift for CFC 11-based foams in appliances does not exceed 4 mW/mK. Another study (reference 4) of foams extracted from appliances after use for up to 9 years gave thermal conductivities in the range 16 8 to 18 1 mW/mK (measured at 0°C) for CFC 11-based foams These are effectively initial thermal conductivities

Based on this analysis and by comparison, cyclopentane-based foams are extremely durable

6 PLASTIC LINER INTERACTIONS

The strong solvent effect of HCFC 141b on PS or ABS liner plastics was effective in prolonging the development time before implementation of the systems in North America The solutions, whilst varying with appliance design, have necessitated modifications in the base plastics or the use of barrier layers incorporated into composites. These result in significant additional costs which will be displayed later

In contrast, all experience with cyclopentane-based foams has shown that the standard plastics developed for use with CFC 11 are suitable for use with the hydrocarbon solution.

7 ENERGY CONSUMPTION COMPARISONS

Whilst laboratory measured thermal conductivities give an indication of relative energy consumptions, reliable data can only be obtained from in use tests of assembled cabinets An average increase in energy consumption of up to 3 5% has been quoted in one study (reference 3).

A recently published paper (reference 5) has indicated the following comparison, relative to reduced CFC 11, shown in Table 4 between cyclopentane-based and other systems

Table 4 - Thermal Conductivity and Energy Consumption

	Reduced CFC 11	HCFC 141b	Cyclopentane
Thermal conductivity	100	98 6	107 6
Energy consumption	100	98	102

This confirms that the thermal conductivity of the foam can only be used as a guide and that the energy consumption of cyclopentane-based foam insulated appliances are only slightly above that for reduced CFC 11-based units

This small change in energy consumption has been compensated for by, at the most, modest changes in unit design

8 EQUIPMENT CHANGES AND SAFETY MEASURES

This is an important topic which requires detailed analysis and only an outline will be provided here Because of the generally inferior thermal insulation properties of all the CFC 11 alternatives, the use of high pressure (hp) polyurethane processing equipment is preferred as it contributes to improving the foam structure

The main changes necessary with the principal alternatives are listed in Table 5 With HCFC 141b-based technology there is the necessity to consider the liner processing step

For cyclopentane-based technology there has to be a professionally conducted audit of the safety precautions for both the trial and production stages The necessary changes are now well established and expert guidance is available from many sources In addition to converting the processing equipment and the door and cabinet moulds and jigs there are two other aspects which it is important to highlight

There should be a safe delivery and storage facility for the bulk cyclopentane The use of drums with the necessary frequent handling should be avoided Ideally there should be bulk tanker deliveries to an underground storage facility which is located outside the factory wall

There must be an emphasis on training of all personnel involved with the process so that agreed procedures are understood and followed The factory management should arrange for periodic audits of the operating procedures.

The flammability issue relates to the handling of the bulk hydrocarbon and the polyol blend containing it There is no relevant effect on the foam or the appliance itself

Table 5 - Equipment Changes

Alternative	Polyurethane processing	Refrigerator jigs/moulds	Sheet extrusion	Liner vacuum forming
Reduced CFC 11	None	None	None	None
HCFC 22/ HCFC 142b	hp equipment plus pressurised blowing agent equipment	New jigs for thicker walls may be necessary	None	None
HCFC 141b	Leak-proof blowing agent blending	None should be necessary	Depending on grade of HIPS or ABS technology new equipment may be necessary	None
HFC 134a	As for HCFC 22/HCFC 142b	As for HCFC 22/HCFC 142b	None	None
Cyclopentane	Precautions to avoid explosive atmospheres	Precautions to avoid explosive atmospheres	None	None

9 COST COMPARISONS

In comparing the costs of implementing the technologies to replace CFC 11 in foams the two main factors are the capital costs to convert the manufacturing plant to operate safely with flammable cyclopentane on one hand and the increased costs of more sophisticated plastic liners necessary for use with HCFC 141b on the other

A study in Korea (reference 5) has given the following comparison of costs which include those associated with the foam, the plastic liner and the capital investment. These are illustrated in Table 6 relative to reduced CFC 11 technology

Table 6 - Total Cost Comparisons

Reduced CFC 11	HCFC 141b	Cyclopentane
100	120 8	110 1

In the context of the conversion of refrigerator and freezer factories in developing countries and the financing of these conversions by the Montreal Protocol Multilateral Fund a study (references 3, 6) was undertaken of the relative costs of implementing the various options in a factory producing 200,000 units per annum The results are expressed in terms of a unit abatement cost (UAC) which is the cost to replace a unit of ODS (ozone depleting substance) The results are shown in Table 7

Table 7 - Cost Comparisons, CFC Replacement

$/kg/year	Reduced CFC 11	HCFC 141b	Cyclopentane
UAC	0 87	5 45 - 15 56	2 62

The range of UACs for HCFC 141b projects reflects the various plastic liner technology options

These studies are in agreement that cyclopentane provides the most cost effective overall option Furthermore, the conversion to HCFC 141b technology may result in additional costs to subsequently replace it by a zero ODP technology

Whilst cyclopentane is typically 50-70% of the price of HCFC 141b (per kg) and less is used in a formulation, the potential saving can be negated by the greater use of other components Foam cost contributions are strongly influenced by the density changes discussed in Section 4

10 FUTURE DEVELOPMENTS

It would be naive to expect insulation technology development to plateau out in the next decade In addition to the programmes to refine the hydrocarbon (including cyclopentane) technology described in section 4 there are other relevant developments in progress

Driven by the need to reduce energy consumption and increase effective internal volumes the use of vacuum insulation panels are being actively considered and are in production in some cases Most of these technologies replace part of the normal polyurethane rigid foam with panel whose thermal conductivity is up to four time less than that of the foam. The energy consumption of the cabinet may then be reduced by, typically, 20%. There are several contending technologies based on silica particles, glass fibres or microcell (open-celled) polyurethane foam Specially developed encapsulating foams based on cyclopentane are available to use with these products They are optimised to flow well in the cavities within the refrigerator walls which are constricted by the inclusion of the vacuum panels

A second development is that of liquid HFC blowing agents These are being evaluated with a view to possible commercial availability about the year 2000. The main characteristics of these blowing agents and the results of early evaluation in US refrigerator systems are shown in Table 8 in comparison to HCFC 141b

Table 8 - Liquid HFC Blowing Agents

	Units	HFC 245 fa	HFC 356 mffm	HCFC 141b
MW		117	134	166
Boiling point	°C	15 3	25	32
GWP	100 yr ITH	950	1160	630
Flammability limits in air	%	None	7.3 - 9 6	7 4 - 15 5
Foam thermal conductivity at 10°C	mW/mK	17 3	17 7	17 7
DoE Energy Consumption		100 9	103 7	100

There are many aspects including these costs and toxicology to be evaluated as well as their effective contribution to climate change which is being studied by application of TEWI (Total Equivalent Warming Impaction) analysis

11. MARKET TRENDS

Cyclopentane-based technology was introduced into refrigerator and freezer production in the Spring of 1993 and is now used by almost all (95%) European manufacturers and several million appliances are now in use The technology was also rapidly implemented by manufacturers in Australia and New Zealand.

As stated, appliance manufacturers in North America (principally the USA) have converted to HCFC 141b This blowing agent will be phased out by the end of 2002 under the Clean Air Act and manufacturers are intensively evaluating alternative technologies which are both zero ODP and help to meet ever more stringent regulations on appliance energy consumption

Japanese manufacturers and their transplants in developing countries have used or considered HCFC 141b and HCFC 22 / HCFC 142b technologies but several are now using or planning to convert to cyclopentane

Numerous developing country enterprises have converted to cyclopentane or have active programmes to do so

It should be noted that any factory which is capable of operating with cyclopentane is already equipped to use the refined hydrocarbon blowing agent technologies now being introduced or other foam technologies under development

12 CONCLUSION

Rigid polyurethane foam technology based on cyclopentane is now well proven and in wide scale use. It provides an environmentally acceptable solution whilst fulfilling all the complex technical demands for an insulating foam in a stringent application

13 ACKNOWLEDGEMENT

The author wishes to acknowledge the assistance of several colleagues in ICI Polyurethanes and of Dr W Bazzo in particular

GMFJ/kd/9/1/96

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CYCLOPENTANE FOAMING ON AN INDUSTRIAL SCALE: INTRODUCTION, RETROFITTING

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Manufacturing Equipment for Pentane-blown Foams for Refrigerators and Panels

by Max Taverna, Piero Corradi and Massimo Castiglioni - Cannon Group

INTRODUCTION

The replacement of CFC11 with Cyclopentane as expanding agent in rigid Polyurethane foams for insulation applications - mainly for domestic and commercial refrigerators and freezers - is today an accomplished task. Being in industrial production in various countries since April '93, this process has passed various tests easier than foreseen: industrial feasibility production, safety, foam's dimensional stability and insulation capacity have all been widely demonstrated in several million refrigerators manufactured and sold world-wide.

Whilst the research continues for the definition of an industrial process for manufacturing domestic refrigerators complying with the soon-coming energy-saving laws, Cyclopentane-blown foams seem to represent the transition solution - for this application - for the next decade.

MARKET SURVEY

European manufacturers have converted their plants and are now producing, or they are able to do so, using Cyclopentane. The conversion of existing plants and the installation of new, dedicated ones has interested all the major groups present in *Western Europe,* as well as those who manufacture in the former *USSR,* in *Poland, Hungary* and in the *Czech* and *Slovakian Republics.* By the end of 1995 all the current European manufacturers will have started their production using Cyclopentane as blowing agent.

North-America still does not use Cyclopentane, preferring HCFC141b for its higher insulation performances, combined with ease of use. This interim solution seems to be perceived as a long-term one, until a new technology - more energy-compliant - will be introduced. Some manufacturers have installed one lab-machine in their R&D Centres to evaluate Cyclopentane, but - to our knowledge - none of them have moved to production with it.

South America: in part due to the World Bank action in assisting the developing Countries in their CFC phase-out program, and in part because of the progressively unavailability of CFC 11-blown formulations, the major *South American* manufacturers have specified all their new plants for using Cyclopentane. We expect *Argentinean* and *Brazilian* producers to start within 1996, whilst the other countries are late in their conversion.

African plants able to work with Cyclopentane have been ordered - or are being discussed in this period - for *Egypt, Morocco, Algeria, Tunisia and Cameroon.* with the help of UNIDO.

In **Australia** and **New Zealand** the market is shared amongst three major suppliers, and we observed two or three factories already in production with Cyclopentane: we can say that in this area the conversion is accomplished.

Asia: *Japan* does not seem to be the right country for this explosive blowing agent. Local regulation on flammable chemicals would imply extremely high costs of conversion. Anyway, several Cyclopentane-capable lab-machines have been supplied, as well as some manufacturing lines for small production series. *China* is moving towards Cyclopentane, using UNDP and UNIDO help: a number of new, dedicated plants have been ordered recently. As far as the retrofitting of existing units is concerned we know of current negotiations only, with no decisions taken yet.

All *South Korean* producers will have some Cyclopentane-capable lines in production by 1995. In *Thailand* one plant was ordered and should be in operation by now.

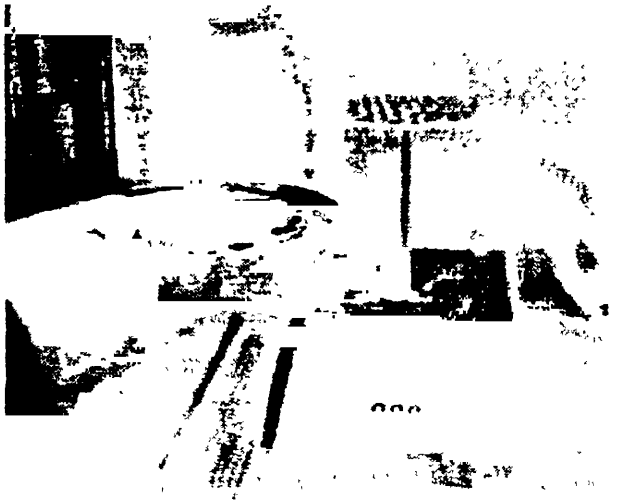
In *Malaysia* and *Indonesia* negotiations are currently held under UNDP supervision.

We know of several negotiations being held in *India, Pakistan, Gulf Emirates, Iran, Syria* and *Jordan.*

As we have seen, the situation is very different according to the geographic area. The trend is not clear, especially in those countries where - together with the CFC substitution program - an Energy-Saving legislation is putting under discussion the use of PU foams as insulating media: the use of vacuum panels, a technically attractive solution seems to be destined to upper-class Refrigerators only due to its costs.

As a matter of fact, the successful installation of more than 100 plants - from our group only -confirmed the following previsions:

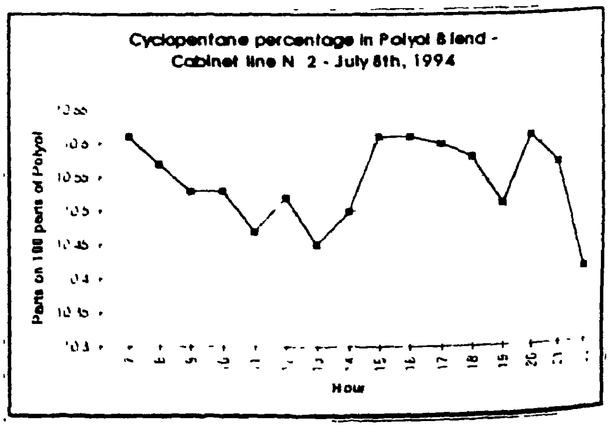
* The *safety measures* suggested since the very beginning of this technology were proper and correct. The use of specific pre blending stations, storage tanks, metering machines, foaming fixtures and related ventilation equipment, gas monitoring networks and electric safeties have prevented explosions and accidents. The careful use of ventilation - a good way in every plant for polyurethanes - reduces the risk of accumulation of Cyclopentane gas in those areas (premixing and polymerisation) where little amounts of Cyclopentane could be emitted regularly. In order to better understand the evaporation behaviour of Pentanes when blended with Polyols - a subject about which no literature has been produced yet - Cannon committed a specific research to the Italian authority in charge of testing hydrocarbons and combustibles. A special equipment was manufactured to test evaporation of blends made with variable percentages of Cyclopentane and conventional Polyol for refrigerator manufacturing.



Testing Equipment for Pentane Evaporability

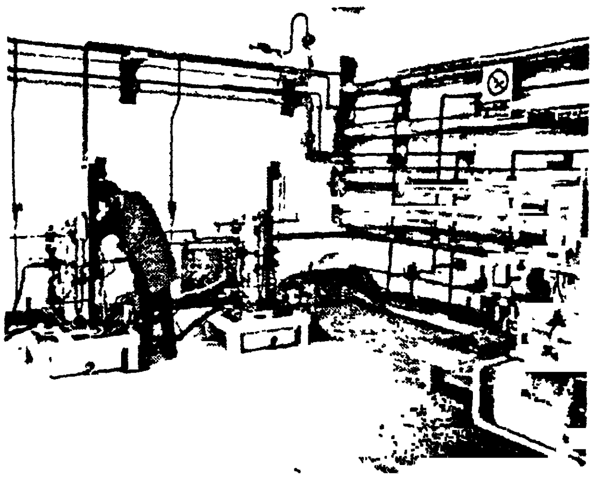
Results of testing highlighted the fact that a Polyol blend containing 15% of Cyclopentane shows an evaporation rate of 80 g/m^2 per hour. The same test performed on pure Cyclopentane gives a result of 4,610 g/m^2 per hour: therefore a commercial blend of Polyol and Cyclopentane shows an evaporability rate equal to 1.73% of the pure hydrocarbon. This low figure allows to take into consideration the amount of pure Cyclopentane only - and not the total blend's - when calculating the quantities present in the production area and in storage.

* The *repeatability of the process* is proven. Dedicated equipment has been designed to mix Cyclopentane to Polyols in desired, programmable percentages.



The graph shows a typical production report of an EasyFroth™ premix unit used at a major manufacturer's site in Northern Italy for blending the Polyol of a cabinet foaming plant. These blending stations usually work unattended, automatically preparing batches of blended Polyol when one of the day-tanks sends a request for a new batch.

In large plants they have been installed in specially built rooms *(see picture, below)*, where all electric components are mounted in one room and all the parts in contact with Cyclopentane are in the contiguous one, totally explosion proofed.



In large foaming factories special explosion-proof rooms can be dedicated to Polyol - Cyclopentane premixing operations.

As we see in the graph all the batches the Cyclopentane percentage remains within +/- 1 % of the set value.

* *Foam's performances* are improving: compared with the early formulations significant steps forward have been achieved. *Flowability* have reached satisfactory levels, also through the optimisation of liquid laydown and filling patterns. Insulation factor measured in real-life conditions, i.e. calculating the energy consumption of various models is equal to that of Freon-reduced formulations.

Dimensional stability is within acceptable limits, partially helped by a slight increase in *moulded density* and *overpacking* to optimise foam's isotropy.

Commercial refrigerators have gone from a traditional 32-33 kg/m^3 density for CFC11 blown foams to 36-37 kg/m^3 for Cyclopentane-blown ones. This increase does not influence the design of polymerisation jigs, manufactured to withstand even higher pressures.

Demoulding time is a parameter deriving directly from foam's dimensional stability and its moulded density and overpacking ratio, and is also affected by the market requirement for thicker walls. All the values of the a.m. parameters worsened in the early days and Cyclopentane-blown foams needed longer demould times. It has been recently reported that formulation adjustments have brought back the demould times to 3.5' for 50-60 mm thick freezers and to 7' for 100 mm thick ones. Shorter demould times seem to be out of target for the time being.

NEW TECHNOLOGICAL REQUIREMENTS

The introduction of Cyclopentane in Polyurethane foams obviously modified some habits in the manufacture of refrigerators. Equipment for storing and premixing Cyclopentane had to be added, metering equipment and foaming fixtures had to be adapted or replaced. Not all manufacturers have the same problems: different products, different manufacturing habits, local legislations deeply influence the choice of production equipment.

Four basic scenarios characterise this industry:

**Manufacturers of domestic refrigerators and freezers working with few models in large lots,* thus not requiring frequent model changes. Formulations are never modified and Polyol/Cyclopentane blends can be prepared in big batches in special rooms, and stored in day tanks that feed several metering units through a pipework.

* ***Manufacturers of small-medium lots of refrigerators.*** A model change often means a different foam's density, that implies the preparation of smaller, precise amounts of Polyol/Cyclopentane blend, as often as they are required by the foaming machine; one blending equipment has been installed in these cases as a back-up to each metering unit, to the advantage of modularity and production flexibility.

**Manufacturers of very large refrigerators and freezers for commercial applications* (supermarkets, restaurants, ice cream parlours, bars). Production lots are small, but quantities of foam injected are relevant, with a proportionally high amount of Cyclopentane emitted per shot. Danger of accumulation of Cyclopentane vapour are high, especially if the polymerisation jigs are scattered on a large assembly hall.

**Producers of sandwich panels* used for refrigerated cells and walk-in coolers, characterised by large panel presses, difficult to enclose in ventilated boxes but emitting large quantities of Cyclopentane vapours per injection.

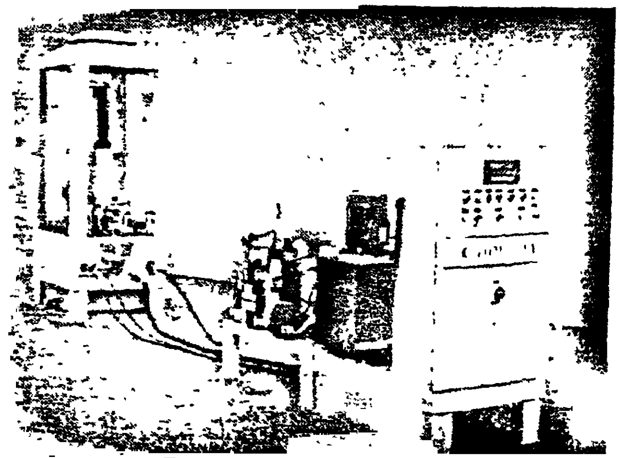
AVAILABLE CANNON SOLUTIONS

Each of these cases requires a specific approach and has a technical solution. Cannon have supplied until now more than 60 different customers in the World and can claim the title of larger supplier of Cyclopentane-compliant foaming equipment. All the range of possible customers and requests has been supplied, from the simplest Polyol/Cyclopentane blending unit to the largest complete plant. Let us review the available solutions that can solve the different problems seen above: all the following examples are taken from supplied plants.

1) **Pentane Storage Stations**, designed above ground when no buildings, roads and railways are located nearby. This solution is easy to be inspected and maintained, and supplies a very good feeding to the Cyclopentane feeding pump.
The underground storage solution is necessary when the above safety conditions cannot be met, or when the external temperature can drop several degrees below zero Centigrade. It allows for an easy gravity-unloading from road-tankers, but requires more attention for the transfer of Cyclopentane to the foaming plant, and is slightly more complex as far as maintenance and inspection are concerned.

Cannon - according to the request of each customer - have supplied until now either the engineering drawings for making a proper storage station, or the specific equipment excluding the tank, or the full installation.

2) **Multi-EasyFroth™** an high-pressure pre blending unit able to prepare mixtures of Polyol and Cyclopentane or LBBA (Low Boiling-point Blowing Agents), with electronically controlled ratio and ventilated safety box.



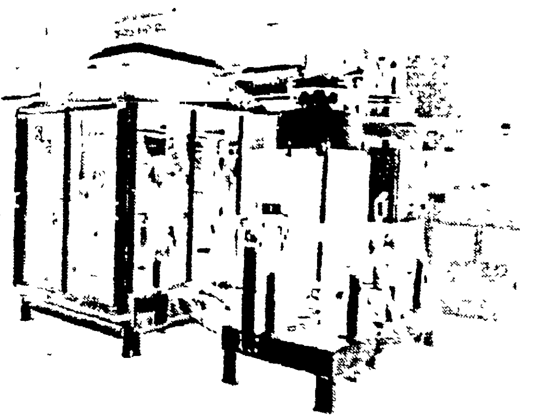
Multi-EasyFroth™, dedicated pre-blending unit for LBBA's and Pentanes

3) **Penta-EasyFroth™**, an high pressure pre-blending unit specifically designed for Cyclopentane and other liquid blowing agents, also available in a split version - adapt to be mounted in two separate rooms. The metering unit is linked with the part of

premix who is in contact with Cyclopentane, and both are in the ventilated box.
The pure Polyol metering section and the control panels are mounted outside it.

4) **Pentamodule,** a complete kit dedicated to the Polyol side of an existing foaming machine, with a tank - fitted with a stirrer operated by magnetic coupling to avoid leakages from the stirrer's shaft - and the high pressure metering section for the Polyol.

5) "**A-System Penta**", a complete high pressure metering machine containing an integrated Polyol/Cyclopentane blending unit under the same section hood.



"A-System Penta", the Cannon unit for producing Cyclopentane-blown foams

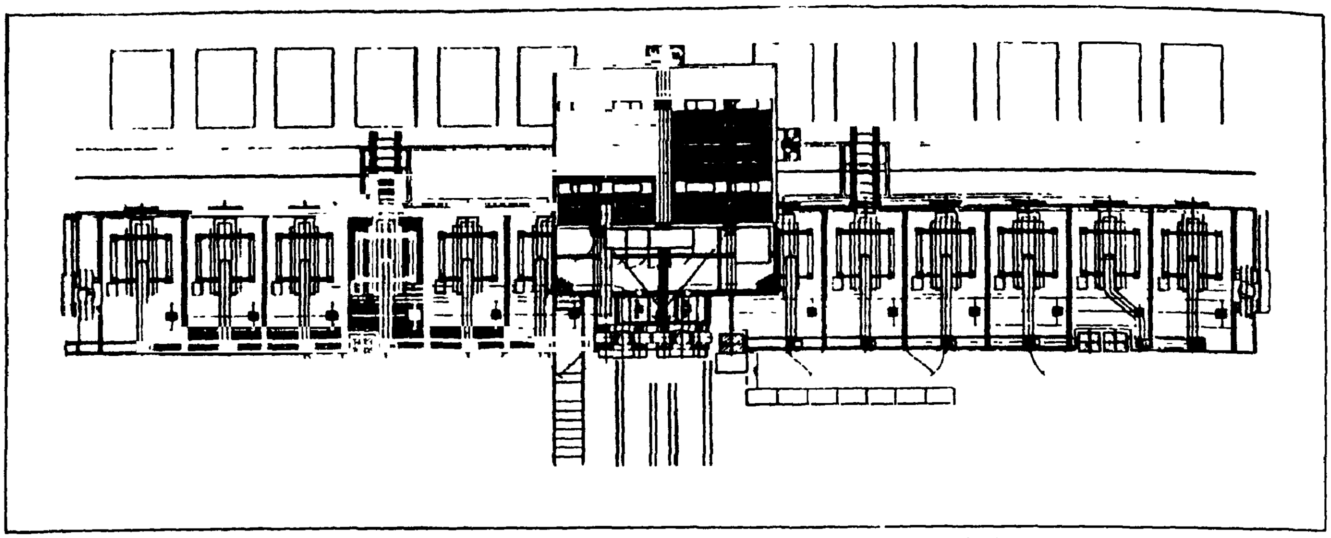
In general, most of our customers have preferred a configuration with the largest possible ventilated box containing all the potentially dangerous components: formulated Polyol tank, high pressure metering unit.

The number of gas detectors can be reduced, the ventilation is optimised, installation of electric components and thorough earthing of all metal parts are simplified.
Specific construction details have been applied to reduce any risk of Cyclopentane vapours accumulation: the whole equipment is mounted on a walkable grid, and suction ducts are mounted on it.

6) **Injection Area.** For the injection and polymerisation area two examples well describe the current trend of this market: a retrofitting solution for an existing plant, and a totally new one.

RETROFITTING AN EXISTING PLANT

As everyone can understand retrofitting an existing foaming plant represents a complex engineering task because it involves more limitations than supplying a new one: several existing technical features must be respected, a detailed technical survey is necessary to make a correct price-estimate, the installation should not interfere too much with the production: week-ends and holidays are the preferred times for this kind of jobs.
The final cost is lower than buying a new plant, but expected savings can be wasted with a wrong approach: the supplier must ensure competent and numerically sufficient personnel for all the phases of the job - estimate, engineering, manufacturing parts, installation, start-up.
Good communications are vital, since a lot of co-operation with the personnel in charge of the existing plant is foreseen.
As a supplier of Polyurethane equipment working through local offices we have had tremendous benefits from our local technical people easily communicating with our customers during these complex retrofitting jobs.
As an example of retrofitting, the following solution shows the case of a multinational company manufacturing refrigerators on two foaming lines of 6 fixtures each.
(see next page, top)
As we can see in the scheme a new mezzanine has been added in the middle of the plant, to hold a box - containing the metering units - and a part of the ventilation equipment. The existing foaming fixtures have been enclosed in a ventilated box, with suction points positioned on the upper and lower sides of each fixture, and a positive air displacement device mounted on the box' roof.



Existing Cabinet-foaming line, Retrofitted with Cyclopentane-suitable injection equipment

A NEW PLANT

Designed to guarantee maximum flexibility and capacity in a very tight lay-out this plant *(see next page, top)* has been commissioned this year to the largest refrigerator manufacturer in Italy. Six ROTOPLUG foaming fixtures, each provided with a rotating plug-holder for a zero-time-plug-change, are mounted in two facing rows of the jigs. Space has been foreseen for a future addition of four foaming fixtures.

The empty cabinets are unloaded from a suspended transfer line, and pre-heated in a large oven until they reach a temperature of 50 °C. They leave the oven on the right or the left side, through two gates closed by sliding doors, and are loaded on two-place carts, that bring them in front of the jig that first will unload a foamed cabinet.

The foaming fixtures are placed in a closed box (classified area, with electric equipment of IP44 execution) fitted with gas sensors and adequate ventilation. Between them - in a service corridor - the mixing heads and their flexible piping can be easily serviced and adjusted.

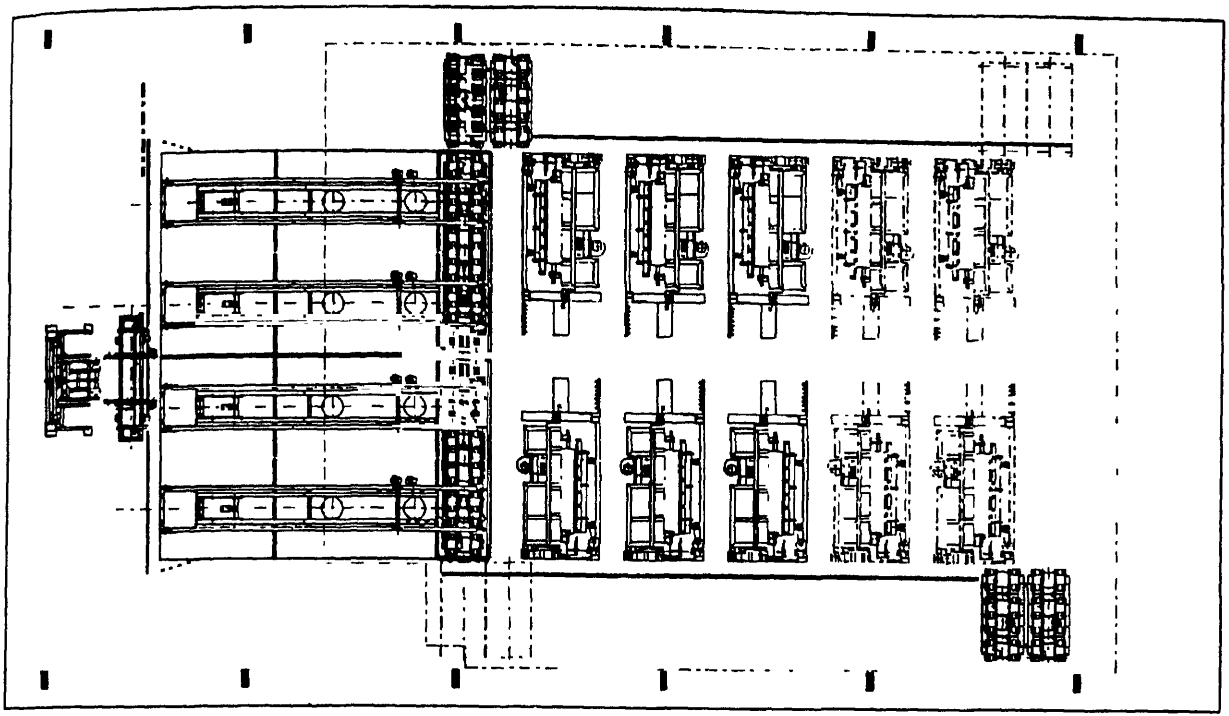
As soon as the jig opens, the door on the box' wall slides up, the foamed cabinet is ejected onto the empty place of the two-place cart, this moves forward one step, th empty cabinet leaves the cart and enters the jig, the sliding door immediately closes, the jig's walls clamp the cabinet and lift it towards the plug.

The foaming cycle takes place and the polymerisation starts.

During the filling phase the Cyclopentane vapour - emitted in a predictable quantity from the venting holes of the cabinet - are captured by the suction system around the jig and sent to the exhaust duct.

All the metering equipment is installed on a mezzanine above the pre-heating oven, enclosed in ventilated box provided with the safeties described before.

The premixing devices and the Cyclopentane storage are installed in separate safe rooms, where all electric components are of E-Ex execution (i.e. Intrinsic Safety Zone). It is interesting to notice that, being a large installation, the Polyol blending function has been specifically engineered so that there is a room fully dedicated to the mixing of Polyol and Cyclopentane, where the presence of electric components has been reduced to the strictly necessary. In a contiguous room, separated by a fire-proof wall, all the motors and electric control panels are installed. Safety is improved, maintenance operation on the electric parts can be run without interrupting the blending cycles, cost has been contained using less expensive electric components.



New Cabinet-foaming Plant, for Cyclopentane-blown formulations

Technical Considerations:

Mould conditioning

The use of Cyclopentane has quickly convinced the producers to switch from electric heating to water conditioning. There are *advantages*: electric resistances are removed from a potentially explosive area, and water can be used as a coolant, should the thermal equilibrium of the mould be influenced by the higher exotherm of partially water-blown formulations. There are *disadvantages*: fitting water pipes on a foaming fixture is more complex than wiring heating elements. Door plants based on Paternoster or carousel system are more difficult to be water conditioned. Fortunately there are *solutions*: Cannon' patented DRUM units are preferred in this case, because a central rotating water collector easily feeds all the moulds mounted on the sides of the rotating machine.

Nitrogen purge of cabinets before injection is still a debated issue. Producers of large cabinets use it, because the amount of vapours is larger and potentially more dangerous. Producers of small cabinets like to have the option - easily obtainable on Cannon's patented L-shaped mixing heads - but not always use it.

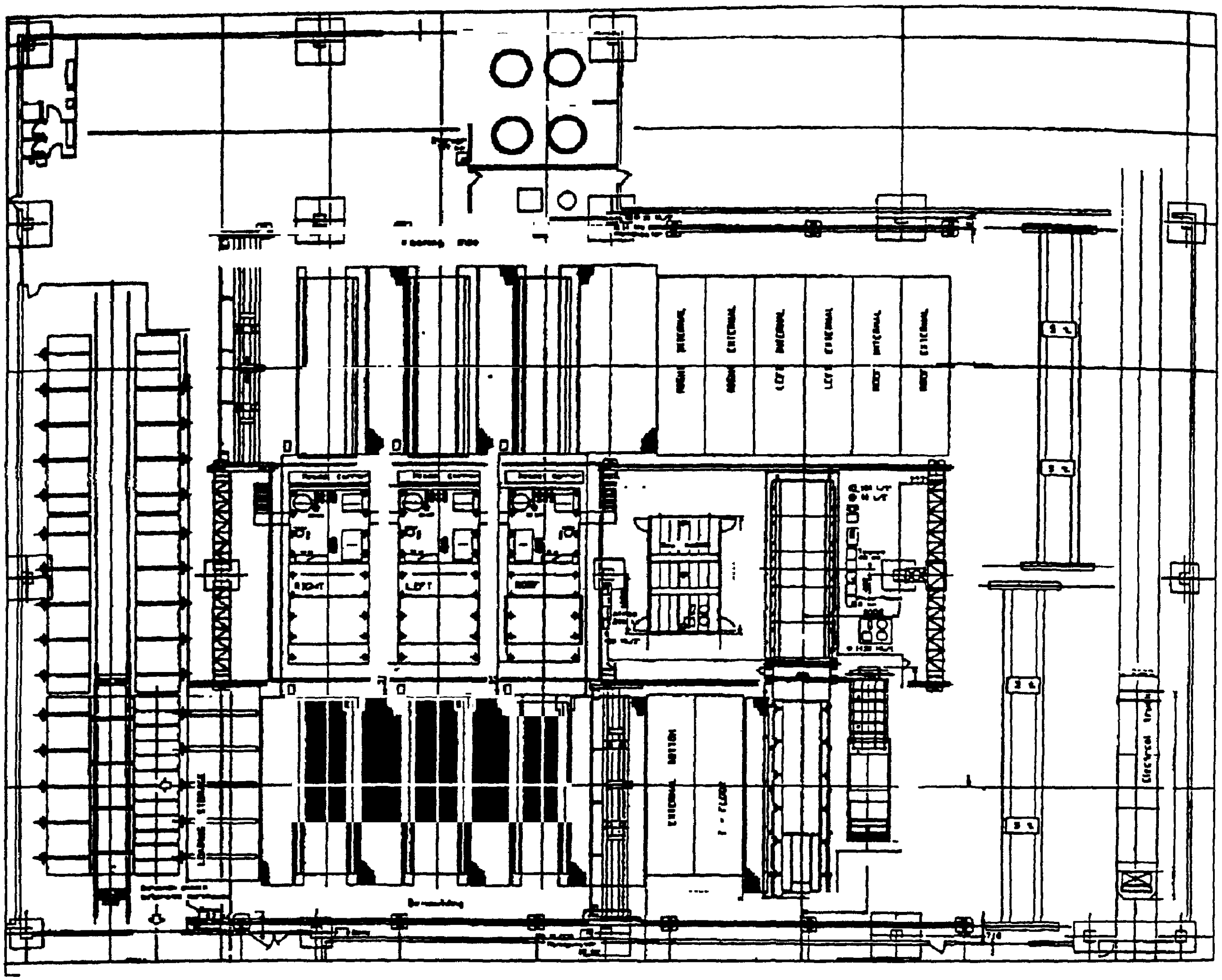
SANDWICH PANEL PRODUCTION

Use of Pentane -blown foams for sandwich panels insulation requires particular attention specially because of the wide size of the production plants: polymerization presses are often as large as 15 x 2 meters, and proper ventilation and gas-detection of the whole area is a major engineering task.

Cannon have just supplied to Mærsk Container Industri in Denmark a large turn-key foaming plant for the production of "reefers", the 40-feet-long insulated containers used for delivery of perisheable goods. Pentane-blown formulations will be useable in this plant, whenever the client will decide to do so. The plant is conceived for the direct injection of PU foam into the two long side-walls and in the roof of the box, whilst the floor is made by glueing thick slabs of XPS (Extruded Expanded Polistyrene) to the metal facings of the panel.

Technical Concept

The whole supply could be described as a sandwich-panel plant, even if its complex configuration goes beyond this description:



Sandwich Panel plant
for insulated Containers

more than 35,000 different "parts" per year have to be made, moved and assembled in the most rational way.

The production plant includes
* 3 Manni presses for foaming sandwich panels 12.5 x 2.5 m large, with a special open-pouring method found to distribute the foam in the most even way on the whole surface of the panel.
* 2 Cannon "A-System 300" dosing units with 6 FPL 24 mixing heads for the open-pour distribution of the foam.
* 1 Cannon Tecnos press for the floor-panel in glued XPS boards, with robot for automatic positioning of Polystyrene on the metal sheets.
* 1 robot for spraying the Polyurethane-based adhesive, supplied by Akzo Nobel.
* 1 panel-storage warehouse, where finished panels are kept until the assembly line needs them
* 1 computerised factory supervision system by Automata, the Cannon Group's electronics division. A token-ring Local Area Network connects 11 knots, 3 being Automata's PC WorkStations and 8 Industrial PLCs, and provides the production manager with all data related with each single function of the plant.

CONCLUSIONS

The use of Cyclopentane as blowing agent for PU foams in refrigerator and freezers manufacture is growing.

Technical constraint due to its explosive nature have been tackled and are being optimised. The successful experiences of these two years speaks positively for the near future.

Energy-saving legislations are pushing for more efficient refrigerators, and alternative solutions are - today - industrially almost available. Cost and manufacture details are still very open points. For the time being, manufactures can look at Cyclopentane as a viable replacement to CFCs, and have their industrial plans on it for the coming 10 years.

For longer .....weather forecast, keep in touch: our crystal-ball is always turned on!

CYCLOPENTANE FOAMING ON AN INDUSTRIAL SCALE: TECHNICAL SOLUTIONS FOR NEW INSTALLATIONS

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Various technological possibilities have been developed in the manufacture of refrigerators for the foaming of housings and doors.

(figure 1 - outline plant possibilities)

The following objective decision criterions have to be considered for the choice of a possibility:

- number of pieces to be manufactured per shift or year,
- grade of automatization, i. e manual or mechanical processes,
- flexibility, i. e. how many different types are manufactured in which unit of time,
- investment expenses/profitability, i. e. after which period of time, the plant will work with profit.

However, also subjective decision criterions, like e. g. usual methods of working with an existing plant, will speak for or against a plant possibility.

On principle you differ between
- stationary foaming plants and
- foaming plants with transfer systems.

In general, a plant with transfer system works economically if more than 10 supporting moulds are necessary.
The use of pentane blown foams supports this trend appreciably, as the safety technical expenditure for stationary moulds multiplies by the number of moulds, whereas for transfer systems, this expenditure is only necessary in the pouring area

Foaming plant for housings

There are the following pouring variants for housings:
- bell position (rear side on the top) and
- tub position (rear side on the bottom).

(figure 2 - pouring variant)

At the beginning of the polyurethane processing in the refrigerator industry, the housing was assembled and foamed in the mould in bell position

However, the bell position has got the disadvantage of a poor foam distribution and ventilation so that, especially due to the quality requirements regarding the distribution of foam density, the tub position succeeded as optimal foaming position during the last years The bell position as foaming position is not allowed when using pentane blown foams, because of safety reasons.

The trend for the foaming moulds changes from single-purpose moulds to change-over and adjustable moulds.

(figure 3 - mould conceptions)

Change-over possibilities exist due to

- core changes
  By which several inner contours and wall thicknesses for the same outer dimensions are possible with one supporting mould.

- core changes and side wall adjustment
  By which several inner contours, wall thicknesses and refrigerator widths for the same refrigerator height are possible with one supporting mould

- core changes, side wall adjustment and end wall adjustment
  By which several inner contours, wall thicknesses, refrigerator widths and refrigerator heights are possible.

Core changes and wall adjustments can be realized manually or automatically.
A quality supporting mould has got the possibility of fine adjustment of the refrigerator dimensions height, width and depth by which the customer can eliminate tolerance variations in the prefabrication.

The principal possibilities for the temperature regulation of the supporting moulds are:

- liquid temperature regulation
- electric heating panel - temperature regulation
- circulating-air temperature regulation.

(figure 4 - principles of temperature regulation)

Liquid and electric heating panel - temperature regulation make the cooling resp. heating of the supporting walls possible within relative short time but are more expensive
The use of electric heating panel - temperature regulation is not allowed when using pentane blown foams

With the possibilities of the automatization technique, the handling jobs

- laying-in of pre-assembled core housings
- pouring
- taking-out of the foamed housing

can be carried out in different comfort up to fully automatic

The laying-in/taking-out is possible

- manually without auxiliary devices
- manually on pallet (figure 5)
- manually on belt conveyor (figure 6)
- automatically over roller conveyor/belt conveyor (figure 7)
- automatically with laying-in/taking-out manipulators (figure 8)

The possibilities for the pouring are.

- manual, mixing head on traversing rail and balancer (figure 9)
- manual, mixing head on traversing carriage
- automatical, mixing head on driven traversing carriage with positioning device
- mixing head mounted at mould (figure 10)
- mixing head on pouring manipulator (figure 11)

The typical change of a stationary foaming plant for housings is shown on figure 12 with

- central feeding line from the preassembly
- distribution transfer device to the stationary moulds
- intermediate storage for empty housings
- preheating oven for each supporting mould
- the stationary supporting moulds
- central retransfer line to final assembly.

The wet parts, metering machine and premixing station, are normally placed on platforms above the supporting mould in order to have shortest possible pipe distances.

Transfer systems as shown in figure 13 with

- central feeding line from the preassembly and preheating tunnel
- laying-in manipulator
- pouring manipulator
- transfer line in curing tunnel temperature regulated with circulating air
- taking-out manipulator
- automatical mixing head cleaning station
- central heating station
- mould change-over station outside the transfer system

will increasingly succeed

These systems have got the advantage of the compact design and the high flexibility.

Foaming plant for doors

When foaming doors it is principally differed between
- pouring into the closed mould and
- pouring into the open mould.

(figure 14 - principle figure pouring variants)

A foam density distribution of higher quality is possible by pouring into the open mould. The decision, whether it is poured into a closed or open mould, essentially depends on the possibility of quick mounting of the inliner including door packing with the outer sheet metal housing.

Also the order of foaming and assembling,
a) - laying-in of outer sheet metal housing
- foaming
- laying-on of inliner,
or,
b) - laying-on of inliner
- foaming
- laying-in of outer sheet metal housing,

decisively depends on the possibility of automatical assembly, whereat in case a) a better ventilation of the interior space is given

The doors are often foamed with release paper or release film as compromise solution and the inliner is mounted in a separate working step.

All handling works in the door foaming plants can be carried out automated, too
- laying-in of outer sheet metal housing
- foaming
- laying-on of inliner
- closing and locking of the mould
- unlocking and opening of the mould
- taking-out of the foamed door

The easiest possibility is the manual operation (figure 15) of the supporting mould and the mixing head

Transfer systems are clearly in the trend for the door foaming.

(figure 16 - vertical transfer with manual charging and taking-out as well as automatical transport, opening, pouring and locking)

Complex systems, as shown in figure 17, will increasingly be successful with
- laying-in manipulators
- pouring manipulators
- automatical opening and closing stations
- cleaning stations
- transfer systems in several levels
- curing line heated with circulating air
- automatical line for sluicing in and out of the supporting mould change-over units with change-over working places outside the transfer system.

The plant controls for housing and door foaming plants are memory-programmable controls which are switched for larger plants as a network via PC.
Mould recognition systems are a necessary prerequisite for flexible automatical plants.
Process and production data are recorded, stored and visualized on screen.

1

Foaming plant for refrigerators

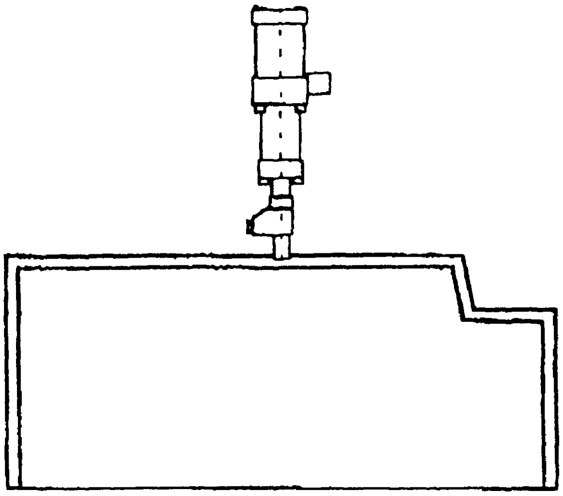
- housing foaming plant
  - stationary plant
  - carrousel plant
    - horizontal transfers
      - oval transfers
      - shifting systems
    - vertical transfers
      - paternoster-lift transfers
      - shifting systems
  - free-programmable transport systems

- door foaming plant
  - stationary plants
  - carrousel plants
    - horizontal transfers
      - oval transfers
      - shifting systems
    - vertical transfers
      - paternoster-lift transfers
      - reverse transfers
        - circular transfers
        - oval transfers
      - shifting transfers

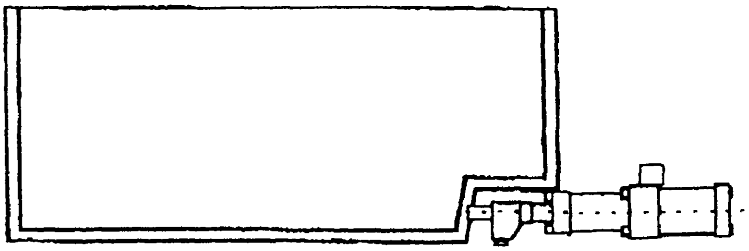
2

Pouring variants housings

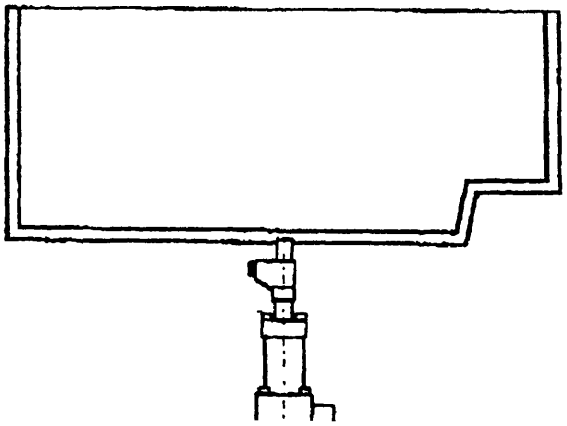
bell position



tub position



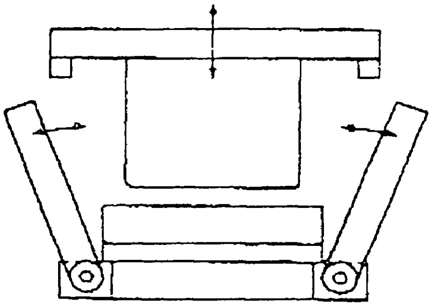
tub position



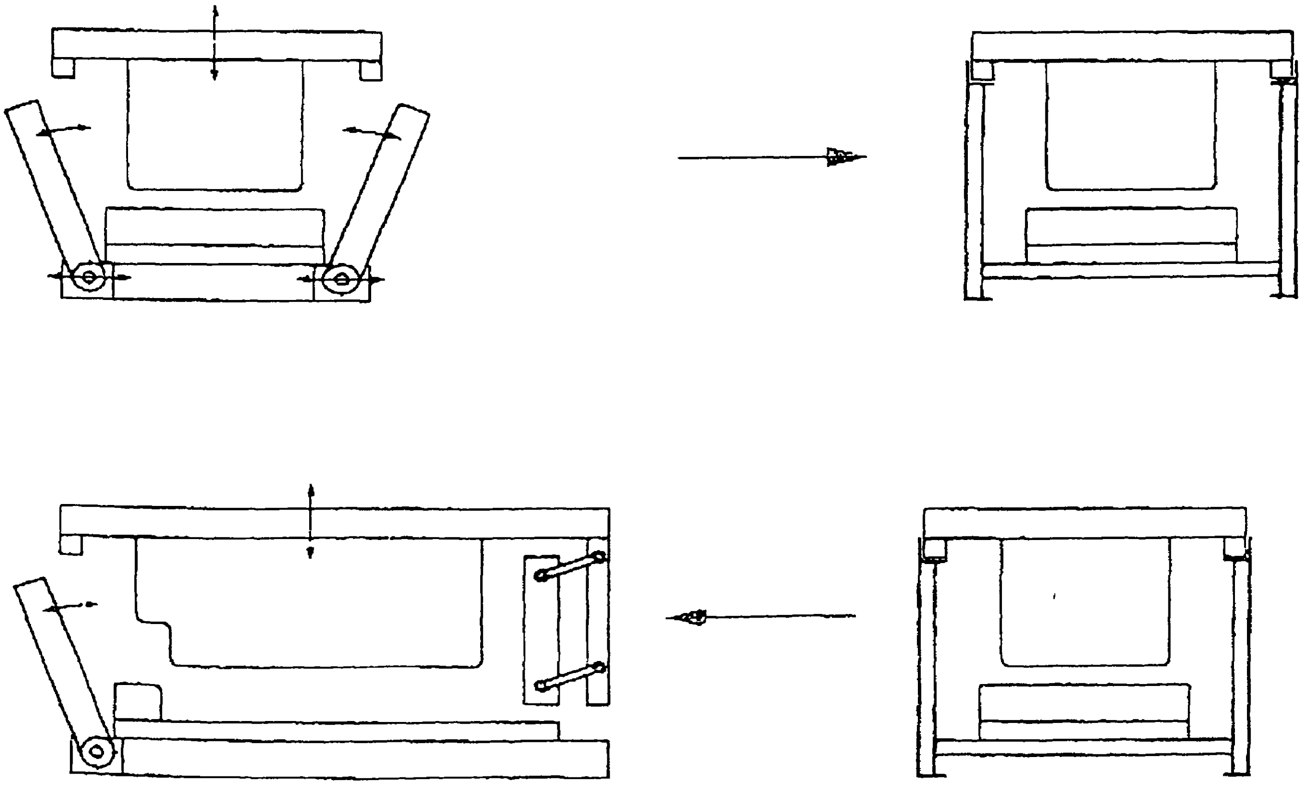
3

Mould conceptions

single-purpose moulds



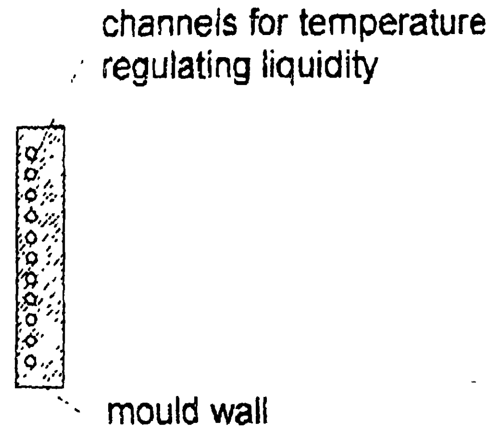
change-over or adjustable moulds



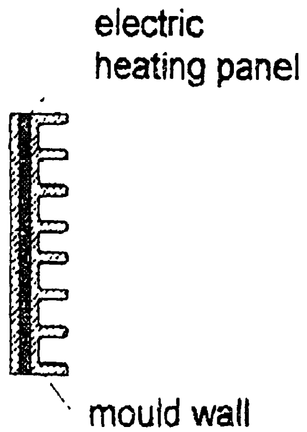
4

Temperature regulation

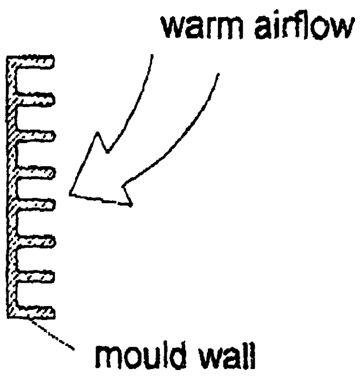
liquid temperature regulation



heating panel - temperature regulation



circulating air temperature regulation



PLASTTECHNIK
GREIZ GMBH
ANLAGEN FUR DIE KUNSTSTOFFVERARBEITUNG

Processing of Pentane Blown Foams

- Pentane Safety Technique -

The dropping of the ozone depleting blowing gases is in full swing

In the Montreal Protocol the world community has irrevocably declared for it The time schedules for the dropping are binding.

In Germany, all ozone depleting blowing gases are prohibited starting from end of 1995. World-wide it is agreed upon a ban up to the year 2000.

What is the alternative?

In many cases the people orientate on the so-called "soft CFCs". Such substances like R22 or R134a have got a considerable residual potential of ozone depletion (ODP = Ozone Depletion Potential) and hothouse effect (GWP = Global Warming Potential)

blowing agent	ODP	GWP
CFC 11	1	1
HCFC 22	0.05	0.35
HFC 134a	0	0.26
HCFC 141b	0.09	0.09
HCFC 142b	0.06	0.36
pentane	0	0.001
CO_2	0	0.0003
air	0	0

An uncompromising alternative is pentane. Pentane is a natural gas without ozone depletion and with a negligible influence on the hothouse effect. Pentane is the **alternative for the future** whereat virtually the same characteristics regarding thermal conductivity and diffusion like with CFC 11 are reached.

Besides plants for pipe insulations and sandwich elements for wall and roof, especially the German refrigerator manufacturers have converted their manufacture by 100% towards pentane blown foams or have newly invested in plant technique for pentane blown foams. With regard to processibility, heat insulation and form stability, c-pentane blown foams are comparable with the known CFC 11 blown foams.

Also with the pentane processing technique developed by Plasttechnik Greiz GmbH (PTG), a number of foaming plants could be converted or newly manufactured within the last two years.

The first CFC-free refrigerator world-wide was manufactured with PTG plant echnique.

entane is a saturated hydrocarbon (chemical C_5H_{12}) in liquid state. Special safety recautions are necessary for the processing of pentane For this Plasttechnik Greiz has eveloped a safety concept from tank up to finished moulded part which has been xamined and certified by the German TUV (Technical Examination Association) in ccordance with the legal bases

Ordinance on Electric Plants in Rooms exposed to Danger of Explosion - ElexV -

Ordinance on Pressure Tanks - DruckbehV -

Ordinance on Plants for Storage, Filling and Conveying of Inflammable Liquids by Land - VbF -

Regulations on Prevention of Accidents and Guidelines according to VBG

EN/DIN VDE Regulations

Explosion-Proofing Guide of Practice BG-Chemie

Water Resources Act - WHG -

he safety concept includes a number of primary and secondary measures which enable aximum safety in their unit and reciprocal interaction, and eliminate human failure to a eat extent

imary Safety Measures

easures to prevent the development of an explosive pentane-air-mixture in all steps processing from tank up to foaming mould)

1 special pipings and sealings
- double seals in case of static connections
- double seals with monitored liquid seals for dynamically stressed sealings at pumps and valves

- all pentane containing tanks are nitrogen-pressurized

- exclusive use of components (e g drives, magnetic switches, transmitters, sensors, switching elements) with Conformity Certificate of the Physical-Technical Federal Institution Braunschweig (PTB-Certificate) or Safety-Technical Certificate of the Federal Institution for Material Testing (BAM-Certificate) in the ex and safety zones

- pentane containing tanks with agitator bushing by magnetic coupling, therefore no sealing and no leakage

- constant ventilation of the polyol-pentane-mixture pump by special ventilation pump

- quantity-controlled nitrogen application in closed foaming moulds with type-certified high-pressure mixing head (patent pending)

- pentane tank storage, underground or overground with double-walled tanks and pipes according to DIN 6608/2 including safety fittings

- locking of the pentane containing plant elements on hardware and software side by switching-off and locking automatics

Secondary Safety Measures
(measures for additional safety in case of average or breakdown)

- housing of all possible leakage points

- exhaustion of all housed plant components by two-stage ventilation system
  - base load during normal operation
  - live load (5-fold air exchange) in case of inconveniences
  - special blower in spark-stopping design

- air flow monitoring by flow sensors at all exhaustion points

- pentane sensors in areas tank, premixing, metering, discharging with evaluation electronic and gas warning system
  - in case of pentane ratios attaining 20% of the lower explosibility limit (UE), malfunction message and exhaustion with live load are switched
  - in case of pentane ratios attaining 40% UE, the plant is switched to currentless (except for exhaustion as well as pentane and blower sensors) and exhaustion with live load

- evaluation units for liquid seals

- potential equalization at all plant components according to DIN VDE 0100

(figure 1: function principle pentane safety technique)

Premixing technique

(figure 2: type sheet premixing station)

The premixing technique is drafted out in this way that the customer can use all possibilities for raw material feeding on pentane as well as on polyol side
The polyol can be delivered from barrel, from container or from tank into the polyol intermediate tank. The same applies for pentane whereat, for refilling from the barrel or container, these are moved into the housed area of the premixing station. With that, the customer has got an absolute safety when charging the premixing station by hand. Especially customer-oriented is the moving slide integrated in the premixing station which enables an easy moving in and out of barrel or container The filling of the pentane into the pentane intermediate tank is carried out by pump (from barrel) or N_2 pressurization (from container).

(figure 3: function principle premixing station)
(figure 4: data sheet)

- The premixing station has got a polyol intermediate tank (filling volume 150 l) with a level control for maximum, minimum and shortage. With this, an automatic refilling from barrel, container or tank is given, and it is ensured, in any case, that no air comes into the polyol circuit

- Polyol and pentane are conveyed in the recirculation circuit before the metering and mixing This way

  - constant pressure and temperature conditions for the whole metering cycle and

  - constant conveying conditions in the measuring ranges of the mass flow meters (measuring principle Coriolis force)

  are guaranteed.

  The premixing station has got separate metering pumps (action principle gearwheel) for polyol and pentane whereat the polyol pump is designed as constant feed pump and the pentane pump is equipped with a frequency controlled drive
  Recirculation and separate metering pumps are the prerequisites for a high-precise metering

- The premixing station has got each a mass flow meter for the polyol and pentane circuit By the volume-related metering the influences of pressure, temperature and viscosity are excluded

- For mixing of polyol and pentane a special static mixer in two-stage design with post-mixing is used With it a mixing high-class in quality is realized A demixing is excluded

The premixing station is manufactured in 3 sizes

(figure 5: premixing station)

Machine tank

The machine tank is equipped with an agitator with magnetic coupling This way, a possible gas leakage at the shaft sealings is avoided

The tank has got a nitrogen connection. Thus, the pentane cannot form a compound with oxygen inside the tank, and therefore no ignitable mixture can form

The tank is connected with a "pressure tank" on nitrogen side, so that no pentane mixture can escape during the filling Machine tank and pressure tank are equipped with pressure relief valves which again are connected to the existing exhaustion pipe

The nitrogen pressure is monitored by a pressure sensor regarding minimum pressure This way, it is secured that nitrogen is always available and an inertisation of the tank is guaranteed.

In case the pressure falls below the minimum pressure, the metering machine is switched off and the valves at the inlet and outlet of the tank are closed.

The machine tank gets an overfilling safety device (tuning-fork-principle). When the overfilling safety device responds, the premixing station and the tank filling will be switched off. No new metering process can be carried out. Only after finding out of the reason and quitting, this will be possible.

The filling level for the refilling and the minimum level in the machine tank are detected via a continuous working probe (float principle with magnetic transmission) The refilling is carried out in a defined range. When the minimum filling level responds, the metering machine is switched off after the end of the shot. No new metering process can follow It has to be refilled

(figure 6: function principle tank)

Metering unit

For the metering unit the reliable high-pressure metering machines of the type series GH-P (P = pentane design) are used. The shaft sealings at the axial piston pump of the metering machine have got double sealings with monitored liquid seals The hand wheel adjustment on polyol side of the axial piston pump is monitored in the same way.

The ventilation of the polyol/pentane axial piston pumps is carried out by a ventilation pump equipped with a magnetic coupling in the closed line system.

Also the shaft sealing of gape-type filter on polyol/pentane side is monitored with a liquid seal

(figure 7: function principle metering unit)

(figure 8: metering unit)

The ball taps in the medium containing pipings have to undergo a special leakage test which is certified by the TUV separately

Pipe connections are principally equipped with double-sealing screwings

inertisation

An inert gas - as a rule nitrogen - has to be used there where, in case of CFC 11 blown foams, air is used to pressurize tanks or something of that kind, as air forms in certain concentrations an (explosive) mixture with pentane

	boiling point (°C)	density at 20 °C (kg/m³)	thermal conductivity (w/mk)	explosion limit (%vol)
CFC 11	23.8	1476	0.09	-
n-pentane	36	626	0.015	1.4 - 8.1
iso-pentane	28	619	0.014	1.4 - 7.6
c-pentane	49	750	0.011	1.6 - 8.7

Therefore a monitored nitrogen ring system with storage is included in the PTG safety concept. With this ring system are supplied

- the pentane intermediate tank of the premixing station
- the pentane tank
- the polyol/pentane machine tank
- mould cavities to be foamed, especially in the refrigerator manufacture.

(figure 9: function principle inertisation)

Particularly when foaming housings of refrigerators, a problematic gas mixture can be formed if the cavity to be foamed is not completely filled due to a faulty metering, in this cavity there is still a pentane-air-mixture and an electrostatic discharge is possible by a mechanical movement.

Therefore the volume to be foamed is filled to 100% with nitrogen.

The nitrogen filling is carried out with the mixing head provided for the foam filling For this purpose the mixing head is equipped with a special filling valve which is operated before the foam filling. The mixing head has been applied for patent and was certified by the TUV.

(figure 10: high-pressure mixing head)

(figure 11: description action principle)

Exhaustion

With the installed exhaustion system it is ensured that the technical safety is guaranteed, also then, when pentane gases are formed because of technical averages or human failure The premixing station, the metering machine with machine tank and the foam filling with foaming mould are connected to the exhaustion

An optimized air guiding in the area of the foam filling and the foaming mould is especially important, as there are the biggest gas concentrations at the beginning of the foaming reaction. In tests it was proved that at the beginning of the cream time there are concentrations up to 20% UE (lower explosibility limit) right over the foam front.

PTG offers the possibility

a) of the partial exhaustion and
b) the complete exhaustion of housings.

The partial exhaustion makes, especially in the operation range, a better accessibility possible. Furthermore smaller quantities of air are required in case of partial exhaustion which leads particularly in regions with climatically caused room heatings to an advantage for the operating costs, too.

The used blower is in spark-stopping design with multi-stage drive Silencer and pipings are tested and permitted for rarefied pentane gases

The air-outlet pipe has to be led over the roof of the operator's building Each single exhaustion point is air-flow-monitored. For that purpose flow sensors according to a calorimetric measuring principle are used.

(figure 12: principle figure partial exhaustion of a supporting mould, patent pending)

Premixing station and metering machine are switched in this way that they can only be put into operation when air flow is indicated at all exhaustion points

At plants with mould transfer, the areas foam filling and evaporation are encapsulated so that the exhaustion is closely situated at the movable moulds for a period of approx 100 s starting from the metering.

Pentane sensor system

Pentane sensors are decentrally arranged in the area of the tank storage, premixing station, metering machine and moulds in order to detect and signal possible gas concentrations

(figure 13: sensor, figure control cabinet)

Sensors according to the action principle heating tone or infrared measuring are used. The sensors are gauged by the manufacturer and have to be serviced regularly

The measured values are analyzed in a central control cabinet and are included in central plant control.

The pentane sensor system causes

a) fore-warning at 20% UE (lower explosibility limit)
   - signal light at control cabinet pentane goes on
   - exhaustion switches to full load (5-fold air exchange compared to base load)
   - defect is indicated at the control cabinet

   After debugging resp. reduction of the pentane concentration, the exhaustion switches to base load, the signal light goes off, the plant can be taken into operation again

b) main alarm at 40% UE (lower explosibility limit)
   - signal light and hooter at pentane control cabinet are on
   - exhaustion switches to full load
   - all machines and plant parts are switched to currentless (except exhaustion and pentane sensor system)
   - defects are indicated at the control cabinet

   After debugging resp reduction of the pentane concentration, the exhaustion switches to base load, signal light and hooter have to be switched off by the operator, the plant can be taken into operation again.

Plant control

All plant elements are provided with a potential equalization according to DIN VDE 0100 in 6 mm² Cu

The electric installation is carried out according to DIN VDE 0165

The control system of the plant technique is equipped with SIEMENS-SPS Separate SPS for the pentane monitoring, the metering machine, the premixing station and the dry parts (stationary supporting moulds, transfer system etc) are used which communicate together on different levels dependent on the size of the plant. On hardware side intrinsically safe and inherent ambiguity safe devices are used for safety-technical pre-connection.

The signalling of gas alarm (20% resp 40% UE) as well as the indication of leakage are to be forwarded to a permanently occupied place during the production rest time. It has to be ensured that, also in case of power failure, the pentane monitoring as well as the exhaustion further remain in function (emergency generator set).

(figure 14: function principle plant control)

SAFE HANDLING AND OPERATIONS DURING CYCLOPENTANE FOAMING

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CONFERENCE ON HYDROCARBON FLUIDS IN DOMESTIC AND COMMERCIAL REFRIGERATION APPLIANCES

ICI Polyurethanes

TITLE: THE SAFE USE OF PENTANE BLOWN RIGID POLYURETHANE FOAM SYSTEMS ON REFRIGERATOR CABINET AND DOOR INSULATION LINES.

PRESENTED AT:

Eco-Refrigeration, the International H.C. Conference held in New Delhi on the 13th and 14th February, 1996.

PRESENTED BY:

J. J. GARDNER

SUMMARY

The presentation is based upon and illustrated by a minimum number of 24 transparencies, hard copies of which will be made available. The subject is discussed from the delivery of pentane to the factory, by road tanker or drum, to the insulated units leaving the P.U. foam insulation lines.

Following is a brief comment on each transparency:

GENERAL

The use of a highly flammable material (Pentane) as a "blowing" agent in the production of closed cell rigid polyurethane foam presents the converter, from polyurethane components to rigid foam, with production and procedural changes of a magnitude never before encountered in our history of development.

Critical areas of the polyurethane foam insulation production lines must be changed to counter the fire and explosion risks associated with the possible emission of flammable liquid or gas. Changes in working procedures, which take into account the hazards arising from the presence of a highly flammable material in the production chain, must be introduced.

The objective of this presentation is to provide a general guide as to where changes must be made, and how well established statutory regulations, covering the safe use of highly flammable materials, provide answers to the potential fire and explosion risks.

TRANSPARENCY 1

The first transparency states, in a very simple way, the nature of the problems arising from using highly flammable materials. Given the presence of a flammable component, oxygen and an energy source, fire is always possible. If the flammable component and oxygen are present in particular ratios and a high enough energy source provided, an explosion will occur.

TRANSPARENCY 2

The second transparency makes the basic point that the transport, storage and use of highly flammable materials, in our case Pentanes, is controlled by mandatory regulations These safety regulations guide the engineer and flammable material end user to the required level of engineering safety.

TRANSPARENCIES 3 AND 4

What we must first understand is that flammable materials are not all the same in terms of ease of ignition, seepage and energy release on ignition. Various authorities throughout the world have drawn up tables, grouping flammable materials on a "risk" basis and indicating the standard of engineering safety required.

Two tables, E.E.C. CENELEC EN50014 and I.E.C 79-1 B.S.4683, are shown to indicate where Pentanes typically fit into the grouping of flammable materials

It is important that the group designation IIA is noted This is important in identifying the correct level of engineering specification required to ensure safe operation

TRANSPARENCY 5

The statutory regulations provide area classification definitions for zones, areas, in which explosive gas/air mixtures will or may occur. The definitions given to illustrate the concept is taken from I.E.C. publication 79-10 Most, if not all, area classifications provided by other authorities use similar definitions

For rigid polyurethane foam producers, it is realistic to engineer the critical parts of the production chain to meet the Zone 2 definitions. Note that the area classification definitions refer to "explosive" gas/air mixtures.

TRANSPARENCY 6

So far, we have identified two important engineering safety identification points. First, pentanes are included in Group IIA of flammable materials, and areas of operation, where explosive emissions could occur, will be engineered to meet Zone 2 requirements.

We now have to look more closely at the Pentane we are going to use. From the table of physical properties of Cyclopentane, we can identify the material characteristics which present particular risks in our production situation and determine the standard of safety engineering to be used. Three properties are critical from our point of view -

a. "Auto-ignition temperature" - related to temperature class

b "Vapour density" - relative to air

c "Explosive limits" - when mixed with air.

For our production chain, we can now identify a third engineering safety requirement, when using cyclopentane as a blowing agent, i.e. the maximum equipment working temperature, T2 (300 C) If n-Pentane is to be used, auto-ignition temperature 285 C, then temperature class T3 (200 C) equipment limits will be applicable.

Pentane gas emissions will be 2.4 times heavier than air and will tend to drop to floor level, rather than rise

Gas/air mixtures within the indicated explosive limits (vol. % in air) of 1.5 to 8.7 must be avoided, usually by dilution with excess air.

TRANSPARENCIES 7 AND 8

As previously stated, the transportation and storage of highly flammable materials is covered by statutory regulations There will be more local variations in the regulations and requirements for this stage of the production chain than elsewhere. However, included will be:-

Road tanker and bulk storage tank specification

Road tanker entrance/exit to/from site.

Disposition of the road tanker, the storage system connection point, and the bulk storage tank - above/below ground, etc.

All the activities and equipment shown must comply with:

Zone 2

Group IIA

T2 or T3

when cyclopentane or n-Pentane is being transported, transferred and stored.

TRANSPARENCY 9

This transparency illustrates how small scale pentane supply systems can be engineered to comply with the Zone 2, Group IIA, T2 or T3 requirements

TRANSPARENCY 10

Working practices will have to be changed, new procedures introduced, etc., in order to counter random potential ignition sources such as, and in particular, an electro-static discharge. In relatively low humidity conditions, line operators and general working conditions can result in significant electro-static discharges occurring In the presence of an explosive gas/air mixture, such discharges can result in fire/explosion.

Wear shoes with conductive soles.

Wear cotton overalls.

Maintain contact with clean steel or concrete floors around the production line.

Use metal tools and containers which can be earthed.

TRANSPARENCY 11

Having discussed transport and storage of Pentanes, we can now look at the blending, blend storage and metering of Pentane/polyol components and discuss how the identified regulations/engineering standards should be applied.

What we are saying is that Zone 2, Group IIA, T2 or T3 must be applied to the following stages:-

Polyol and Pentane component blending,

The storage of a polyol-Pentane blend,

The metering pump for the polyol-Pentane blend.

TRANSPARENCIES 12 TO 15

The following four transparencies illustrate how the Zone 2, Group IIA, T2 or T3 requirements can be applied to the activities of:-

Polyol/Pentane blending,

Polyol/Pentane blend storage,

Polyol/Pentane blend metering.

The main features of the engineering, in addition to the Zone 2, Group IIA, T2 or T3 compliance, are:-

Enclosure of critical equipment,

Extraction, constant during operation,

Pentane gas detection,

Earthing.

The pentane gas detectors should be calibrated to detect Pentane emissions well below the lower explosive limit (L.E.L.) It is suggested that a warning should be given at 10% of the L.E.L and the volume of the air extraction system should be increased. If the Pentane emission continues and increases to say 25 or 30% of the L.E.L, the Pentane supply must be shut down to all parts of the line and emergency procedures followed.

TRANSPARENCY 16

In order to reduce the cost of converting a rigid polyurethane foam production line for the safe use of a Pentane blown system, some pieces of standard electrical equipment can be removed to a specific minimum distance from a high risk area and put under a slight positive air pressure. So doing would prevent any flammable gas emissions from entering the equipment in the event of an accident.

TRANSPARENCY 17

The protection of critical areas of the polyurethane component processing line is achieved by.-

Correct electrical specification,

Ventilation, under pressure, over pressure,

Enclosure of equipment stages/activities,

Earthing of each stage/activity on a common system,

Monitoring for Pentane gas emissions.

It is important that work procedures should be reviewed and, where required, replaced or upgraded to take into account the risks associated with the possible presence of a flammable or explosive gas emission.

TRANSPARENCY 18

It should be remembered that containers and equipment, which have been in contact with or contained Pentane or polyol/Pentane blends, can also present a fire or explosion risk when empty or transferred to other activities, if flushing procedures are not followed Correct and comprehensive procedures should be written up for the decontamination of equipment and containers

TRANSPARENCIES 19 AND 20

Pentane gas emissions occur during the polyurethane component dispensing and expansion stages in either a free rise or refrigerator cabinet insulation operation High concentrations of Pentane gas can be detected close to the surface of a free rise foam or at the breathing holes exhausting the free air from inside a closed volume being insulated with Pentane blown rigid P.U. foam Measurements and calculations suggest that less than 5% of the Pentane injected into a container is lost during the polyurethane foam expansion process. Where the flow characteristics within a refrigerator cabinet or door are good/easy, the loss of Pentane gas can be as low as 2.5 to 3.0% by weight.

Based upon the measured/calculated Pentane losses, it is possible to estimate how much flammable gas must be collected during the various insulation processes

Pentane emission from a closed volume, which is being filled with a rigid P U foam, will vary from zero at the start of the foam expansion, to well over the lower explosive limit (L.E.L.) at the end of the foam rise

We can now estimate how much Pentane gas will be emitted into the workplace and when it will be emitted during the insulation of a refrigerator cabinet or door.

TRANSPARENCIES 21 TO 23

Once again, Zone 2, Group IIA and T2 or T3 standards must be adhered to in the dispensing and rise stages of the polyurethane foam insulation of refrigerator cabinets and doors The risk of emission of flammable gases exists from the start of injection to the end of the foam rise. During this ± 60 second period, the foaming jigs and the adjacent production line area must be treated as Zone 2

Enclosure, extraction, earthing and Pentane gas detection must be applied to ensure safety

It is more important than ever to remember, at this stage of production, that the Pentane gas emissions, being 2.4 times heavier than air, will tend to pool or collect below the jigs and flow into the lowest parts of the factory Service ducts and access spaces below the factory floor must be vented or sealed to protect them from accumulations of Pentane gas.

The Pentane gas detectors should be calibrated to detect emissions at 10% of the L E L A warning should be given and an increase in extraction capacity should occur If the Pentane gas concentration continues to rise an alarm should be given at 25 to 30% of the L E L and the production of cabinets or doors should be interrupted. The cause of the increasing concentration should then be investigated.

TRANSPARENCY 24

Safe production, using Pentane blown rigid polyurethane foam systems, is achieved by:-

1. **Identifying the critical work areas and production operations**

2. **Applying the appropriate safety techniques and engineering standards discussed**

CONCLUDING NOTE:-

Accidents and emergencies can and will occur/arise on the best designed and constructed production lines. With such events possibly giving rise to the emission of a flammable liquid or gas, it is important that the production line workers and factory management have clear and comprehensive emergency procedures to follow

At the very least, staff must know what action to take when a Pentane gas emission is detected and the alarm given. In the event of a breakdown or emergency, staff must not be left to take whatever action they feel is appropriate

CONCEPTS AND EXPERIENCES IN SERVICING OF REFRIGERATION APPLIANCES

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LIEBHERR-INDUSTRIEANLAGEN AG

ECOFRIG
Hydrocarbon Conference
Delhi 13.-14.02.1996

Concepts and Experiences in servicing of refrigeration appliances (mainly Isobutane / R600a)

Jürgen Melzer
Industrial Engineer

Franz Steinrock
Technician

CONCEPTS AND EXPERIENCES IN SERVICING OF REFRIGERATION APPLIANCES

1. INTRODUCTION

Yesterday you have watched the practical demonstration of a R600a refrigerant repair with the LIEBHERR designed repair equipment. It had been a long way, with new developments and practical experience to come to this actual situation, where such equipment is free available on the market.

As a reminder, let us shortly resume, how this happened, why we had chosen R600a as refrigerant and what are its main characteristics.

Until 1993 we had used R12 as refrigerant in domestic appliances. In April 1993 we changed our whole production programme (nearly 400 basic models in 2 factories) to R134a within 2 weeks.
Simultaneously the whole service network was adapted to handle R134a beside R12 too.
This wasn't a difficult task, as the equipment needed for R134a is nearly the same as for R12. Only Estheroil and different joints / sealings had to be used.
We also recommended to use Lokring connections, as soldering creates oxidisations that will be dissolved by R134a.
It can then create obstructions in the cooling circuit.
As Estheroil (R134a) and Mineraloil (R12) don't fit together, we opted to supply all service stations with a second set of repair equipment for R134a.

At the same time it was obvious that R134a wouldn't be accepted by German consumers for a long time, due to its high GWP potential. Hydrocarbons or blends of it were already known as refrigerants, but not yet ripe for mass production. The final decision was R600a.

It is a flammable gas, with the chemical formula $C4H10$ and has:

- ODP zero
- GWP nearly zero
- an atmospheric life span of only 2-3 days
- a boiling point of -11,7 °C
- is explosive as air mixture between 1,8 and 8,4 Vol. %
- is colourless and odourless

LIEBHERR started with R600a in February 1993, when first samples were produced and sold and mass production of specific R600a models started by mid 1993.
As for the production, no real experience existed how to handle this gas in day to day business and according to which standards and regulations.

2. SERVICE CONCEPT

To conceive a service concept for repairs in the cooling circuit of R600a appliances at the customers jobsite, nearly the same conditions apply as for the mass production with Hydrocarbon R600a at the final assembly.

These criterias are:

- to avoid any explosive mixture of gas/air
  (contrary to production, no gas detectors will be possible)
- no ignition source
  (the ignition temperature is around 530 °C)
- the quantities handled are rather small
  (approx. 20-50 gr. - like one or two small cigarette lighters)

First repair necessities arose by end of 1992 at the German Foron company, that used a mixture of Propan and Isobutane. At that time the gas used to be burnt out and filling was done with small cartridges, containing the exact needed quantity. It was not a professional procedure at that time.
Mainly appliances were brought back to the factory for repairs.

2.1 LIEBHERR SERVICE CONCEPT

When LIEBHERR started in 1993 with first R600a models (only 1-2), we also used these cartridges at first. But then intensive work began to conceive a professional concept, which was finalized in early 1994

The main problems had been:

- filling cylinder isn't possible, as R600a doesn't have a plain surface in a bottle or cylinder. It lies higher at the border and lower in the middle. For the exact filling quantity required, only weighing seemed feasible.
- flexible hoses, resistent to R600a. Finally we succeeded to find a gas- and acid resistant hose in the pneumatic sector.
- to find a suitable quick connection valve, 3-way. The Schrader valve was found suitable.
- only to use parts approved by German TÜV.

Other small problems were solved.
Then we looked for an industrial partner to produce this equipment in larger quantities.
Later on, it had been copied by other companies and is nowadays everywhere in use.

The result of all the before mentioned developments and experiences is the service repair set that you have seen the day before.
This set consists of:

1. Filling device for R600a
- 2 bottles of R600a (net content 450 gr. each)
- set of manometer, precision regulating valve with filling hose and quick coupling
- digital precision scale
- portable case for these items

2. Lokring equipment
    - different tools for various kind of Lokring connections
    - valves
    - filling tubes, reduction tubes of different materials
    - alu case for a.m. items, portable

3. Piercing pliers
(for filter drier and filling tube)

4. Connection couplings

5. Leak detector

As the R600a quantities in the cooling circuit are much smaller than for R12 we recommend to check the leak rate in an even smaller range. Hand carried leak detectors with leak rates above 10 gr./year should not be used.
We use 3 gr./year.

All items of this repair set are available on the market and can be purchased at special companies (Lokring, Refco, Kältefischer etc.)
The prices are roughly DM 3'500.- for items 1-4 and DM 2'500.- for a good, reliable leak detector.
It is understood, that the other, usual equipment of a service technician is available as well:

- various tools
- nitrogen gas bottle
- vacuum pump, 2 stage, 3,5 m^3/h
  (filled with Esther oil, which is less hygroscopic than mineral oil)

This service concept is applied now by the most main European refrigerator manufacturers.

Nowadays, there is even a repair equipment available (vacuum pump, filling device, Lokring, etc.) that can serve all three refrigerants (R12, R134a, R600a), but with separate valves and hoses for each refrigerant.

2.2. BOSCH-SIEMENS CONCEPT

The only company known, that didn't use the b.m. procedure is Bosch-Siemens. They still use the initial system with various cartridges of different weight. The weak point of this system are the simple valves used (for cost reason) that are not always 100% tight. For this reason you are not always sure to have really filled in the total quantity.
We have indications that Bosch-Siemens will also change soon to our system.

3. SERVICING PROCEDURE

For any repair procedure you will need the before mentioned equipment (see 2.1) and you have to obey the main basic conditions and instructions (see 2.). The repair procedure, as shown yesterday, is

Exhaust the refrigerant on the pressure side into the open air

1. Plug into the system with the first pliers at the filter drier and connect hose.
2. Open the pliers and let discharge the refrigerant with the 5-meter hose (out of the window).
3. Connect the compressor to the main electric supply (electric socket).
4. Let the compressor run for five minutes.
5. Pull out the plug for about 1 to 2 minutes, then have the compressor run another 5 minutes.
6. Close the pliers at the drier.

Discharge the remaining refrigerant on the suction side.

7. Connect the second pliers with the vacuum pump. Plug in at the filling tube.
8. Evacuate the remaining refrigerant with the vacuum pump.
9. Once the pre-set absolute vacuum setting is reached, let the vacuum pump run another 10 minutes.
10. Disconnect the vacuum hose and both pliers.

Disconnect the pipe connections and prepare the new connections.

11. Cut all necessary connections.

12. Seal the pipe-ends with rubber caps.

13. Change compressor (if this is the defect part).

14. Begin working with the new compressor. Connect the pipes with the Lokring system. Blowpipes or open flames are never allowed.

15. (When servicing with Lokring connections, follow the manufacturer's instructions closely).

16. Use the service drier and apply Lokprep sealing compound sparingly.

17. Lokring connections must be made cleanly and carefully.
Wait for three minutes after use of Lokprep before any pressure test.

Pressure test with nitrogen.

18. Connect nitrogen bottle with filling tube.

19. Conduct a pressure test, but not above 8 bar.

20. Check all the connections (with a leak spray out of a bottle; it's a kind of soap water). Lower pressure and let the nitrogen escape.

Evacuating

21. Connect vacuum pump. Evacuate on the suction and pressure side until reaching the point of absolute vacuum. Let the vacuum pump run for another ten minutes.

22. Connect the Isobutane bottle with the valve and vacuum pump by means of the filling hose.

23. Before ending the evacuation process, the hose connection to the filling cylinder must also be evacuated to free the system entirely from all residual gases.

24. Check the Isobutane cylinder. Make sure the degree of purity is 2.5. (Quality level on the "Linde" bottles)

25. The cylinder pressure must be above 1 bar - otherwise the pressure cylinder must be heated in warm water.

26. Open the cylinder valve.

27. Switch on the scales and measure the gas volume in the cylinder (by weight).

28. Adjust the tare to O.

29. Open the hose valve to allow the refrigerant to flow into the cooling circuit. The refrigerant flows in slowly, allowing accurate filling. After about 2 minutes, switch on the compressor.

30. Filling should be accurate to a gram.

31. Close the hose valve and switch off the scales.

32. The filling operation is completed. Take-off the quick-action coupling (Schrader valve)

33. Screw-on the protective cap, after having applied some Lokprep.
34. Check all the connections again with the electronic leak detector.

Nowadays a LIEBHERR service technician has the following equipment:

1. complete set for the use of R12, vacuum pump with mineral oil
2. complete set for the use of R134a, vacuum pump with Estheroil
3. complete set for R600a, the vacuum pump can be used from the R134a set

4. CONCLUSION

The experience of the last years has shown that Hydrocarbons can be handled safely in production and after sales service.
Until today LIEBHERR alone has produced more than one million R600a refrigerators and in all Europe it will be more than 3 million.
Not a single accident occurred during production nor in the use of these appliances. There had been however some minor incidents in the first days of servicing, when R600a was burnt out.
This is now excluded, when you use the proposed service equipment.
Our actual service statistics shows that

- more than 60% of repairs are on R134a and
- only 40% on R12 and R600a together.

General defect rates on R600a systems are similar to R12, whereas for R134a it is the double.

In this connection let me give you some remarks on our R134 a experience.

We have used R134a since April 1993 and will phase it out in production by end of 1996. During this period we faced a lot of problems in production as well as in servicing.

Some of these problems had been:

- accumulation of paraffin in the system (compressor manufacturers fault).

- in case of repair soldering, small oxidation occur. These are dissolved by R134a and may block the capillary tube or spoil the valve reed (plate). This problem was solved with Lokring connections.

- accumulation of humidity will block the system.

- 50% of all service needs are noise problems. Accumulations of oil residues narrow the flow and create noises like a "waterfall".

The repair consists of a rinsing from the suction side with warm refrigerant (50-60 gr., 50 °C) and flushing with nitrogen to dissolve the oil residue. If too much oil is flushed out, a new compressor way be required.

- production after shift change

Components were left open (no rubber caps) during shift change Result: Increase of humidity.

- laying of appliances during transport

Estheroil is very thin and will flow into the evaporator. If after set up, the appliance is immediately put into operation, thickening and/or resinifications may occur and tie up the system, that results in compressor failure.

This list of different faults shows that we - and especially our service people - are glad to abandon the use of R134a.

With the introduction of the "R600a" Isobutane non-ozone-depleting and energy-saving refrigerant, LIEBHERR has set new standards.
LIEBHERR is committed to meet the ecological challenge by manufacturing environment-friendly products utilising the very latest technology.

Hydrocarbon Refrigerants: Training Needs.

Jane Gartshore, Cool Concerns, UK

Introduction

This brief note should be read as a supplement to the paper for the session entitled "Hydrocarbon Refrigerants: Properties, Purity and Safe Handling" The extensive technical and safety information in that paper should form the basis of the training content for a serviceman handling Care refrigerants (Hydrocarbons) in India. This content has been carefully developed and is well proven in the UK where some 1500 engineers and technicians have attended 51 Calor courses (as at December 1995).

However, there are obviously very great differences between the refrigeration and air conditioning industry in the UK / Europe and India. Before undertaking the analysis of hydrocarbon training needs for India, five significant factors need careful scrutiny.

1. The NEEDS Analysis.

Virtually any problem in industry or commerce can be put down to insufficient staff training. Ten to 20 years ago scientific management principles set great store by "Training Needs Analyses" (TNAs). Nowadays most businesses are aware that training is only part of a solution to a problem. Some problems which start as a perceived training requirement turn out to be a design, machine or organisation problem.

It is recommended that the approach to this subject in India should firstly be a **Needs** Analysis before evaluation of the training requirements.

2. Fabricators / Assemblers

The structure of the refrigeration and air conditioning industry in India includes many small assemblers of freezers and air conditioners. The "tolerance" of CFCs enabled these size enterprises to start up and flourish. Adoption of R134a, other HFCs, hydrocarbons and mixtures thereof will each involve fundamental changes in practice for these enterprises.

There is a considerable training need in this area which would entail a broad training programme for all fabricators including such things as workplace layout, siting and storage of refrigerant, competent supervision. Many fabricators will need very basic training covering appropriate system design.

3. Base Knowledge

In Europe the regulatory frameworks over consumer protection, public liability and health and safety are impediments to an unqualified person setting up as an appliance serviceman. The UK refrigeration and air conditioning industry has a registration scheme involving an assessment of the knowledge and practical skills of refrigerant handling. Hydrocarbon refrigerants and their potential hazards are included in this assessment.

Clearly a serviceman's training for hydrocarbons will be dependent in his base knowledge. In the UK the hydrocarbon training has been an "overlay" on basic craft knowledge and skills. Someone handling hydrocarbons in a home or public place without a good understanding of refrigeration components, operation of systems and correct service procedures will present extreme risks to life and property.

4. Current Quality / Safety Performance

The Calor training course covers hydrocarbons as "drop-in" replacement for domestic appliances. We recommend that there should be an assessment of any risks associated with particular appliances. Some units may have a known weakness or a propensity to failure. This information would be a vital part of the training.

5. "Institutional" Aspects

The special training needs of India to accommodate and take full advantage of hydrocarbon refrigerants will involve commitment and contributions from the institutions involved.

The Panel discussions of this Conference will provide an important opportunity to explore ideas, agree on priorities and direct the way forward.

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ECO-REFRIGERATION CONFERENCE

FEBRUARY 13-14, 1996

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